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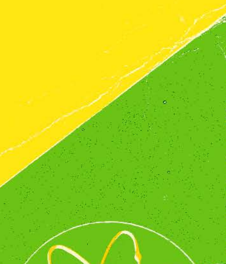
ADVENTURES IN CHEMISTRY

John H. Woodburn



ADVENTURES IN CHEMISTRY

(Original title:
Excursions into Chemistry)

JOHN H. WOODBURN

Coedition LADDER, Ed. NEO-CARTHAGE
at the 4000 - word level

Coedition LADDER, U.S.A. Ed. NEO-CARTHAGE

These books are specially prepared editions of well-known American books. They have been made easier to read the enjoyment of readers for whom English is a second language.

This book uses 4,000 English words. Some words in the book are above this step and will be found written in boldface letters. They are explained in the Glossary at the back.

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NOTE TO READER

The names of many elements and chemical compounds are mentioned throughout this book. There are two lists in the back of the book to assist you. One list contains all the elements, their atomic weights and symbols; the other contains those chemicals and compounds with their symbols that have been used in *Adventures in Chemistry*.

1

INTRODUCTION

Chemistry has always appealed to people who enjoy learning about substances and their properties. To those who believe that any substance can be improved, chemistry excites and challenges the imagination.

Because chemistry is the science of the change and interchange of atoms and molecules, chemists study a variety of problems—the drug that often, but not always, cures a disease; the plastic that shatters when it becomes too hot or too cold; the dye that fades when it is exposed to too much sunlight; or the fabric that becomes old and worn too soon.

The production of food by plants and animals; digestion, which leads to the release of energy for work or leisure; the growth of muscles, bones, or nerves—these all involve the rearrangement of atoms in molecules.

Producing fuels to power the world's engines and purifying these fuels from their raw sources; the growth of wood or the production of plastics, metals, and all other building materials; growing wool, cotton, and silk; or making nylon and thousands of other new substances—these, too, are parts of the world of chemistry.

Many events that occur are actually atomic or molecular in nature. The roar of a forest fire, the flash and thunder of lightning, the sudden release of energy in an explosion—these happenings are the results of the action and interaction of atoms and molecules.

Chemistry in one form or another is a very old science. There have always been men and women who wanted to improve on the things of nature. Centuries ago, artists tried to discover ways to give the **pigments** in their paints more permanence and brilliance; swordmakers searched for a kind of steel that would make sharper swords; doctors looked for plants and flowers that could cure pain and sickness; and glassmakers were eager to learn to make better glass.

Evidences of the success of chemistry are seen everywhere. Display counters in department stores, drugstores, and other kinds of shops show one kind of success. Another kind is derived from the satisfaction of solving difficult problems. Indeed, to some chemists, problem solving results in a greater satisfaction than merely producing a new or improved material.

Of course, chemistry has its disappointments as well as its satisfactions. It requires certain skills, qualities, and a determination to work until a project is completed. Fortunately, few kinds of work seem to attract people and urge them on to success more effectively than does the pursuit of chemistry. There is something about chemistry that awakens the inventive and exploratory spirit of men and women, something that keeps chemists in their laboratories night and day, watching the first signs of success begin to show in their **test tubes** and **flasks.**

Types of Chemistry Projects

Because chemists do such a variety of things, each chapter of this book will present a different type of project.

One kind of chemistry project encourages the experimenter to try to determine what kinds of elements or chemical compounds are contained in a substance. For example, you may know about a substance that is sprinkled in fireplaces to give the flames different colors. Although the container may have the contents written on it, it would be interesting to know which compound causes a particular flame color. With the experience gained from this project, you may want to attempt to discover why some kinds of wood make colored flames although no special substance has been sprinkled on them. Or you may want to try to make a better substance for coloring fireplace flames, a substance that gives a better variety of colors or continues to burn for a longer period of time.

Another interesting type of project is how to **extract** a substance from another substance and then purify it. Consider the scent of a flower, for example. Obviously, the entire flower does not give the flower its wonderful smell. There must be a substance in the flower that is the perfume. The mind and ability of a chemistry experimenter will be challenged when he attempts to obtain a very small quantity of the pure flower perfume. If you do not use your mind, or if you are not careful with your hands, you may either destroy the delicate perfume molecules or lose them in your efforts to separate them from the other molecules of the flower. Actually, you may want to begin your work in "extract and purify" projects with something less difficult than a flower's perfume, and gradually proceed to complex and delicate substances.

Another type of project begins with substances that are already available and then proceeds to produce new substances that are more useful or interesting. For example, people now have many kinds of plastics with which to experiment. Each kind has its own different properties. There is an equally large variety of dyes and pigments available. But when this book was being written, there was no plastic with exactly the properties needed to allow it to be sprayed on eyeglasses to make them darker. People who wear eyeglasses could use such dark glasses as a protection for their eyes from bright sunlight. Surely people who wear eyeglasses would appreciate such a material. Perhaps the substance could be sprayed on the windows of an automobile, and then removed when the driver no longer needs protection from a glaring sun. An interesting project would be to try to develop such a spray-on, pull-off protective plastic. Many kinds of valuable projects depend on recognizing the need for new or improved substances, and then creating a required substance.

A person does not progress far in the study of chemistry without realizing that the action in chemistry occurs between completely invisible atoms and molecules. It is easy to see or feel, or weigh and measure, tiny bits of solids or small drops of liquid, but chemists know that the **reactions** they are trying to produce involve particles, or very small bits of material. The simplest chemically distinguishable particles in matter are called the atoms of the elements. Some of these atoms can bind together in preferred patterns to form the molecules of chemical compounds. The complexity of atoms, and their arrangements in molecules, are important in determining how chemical reactions occur. For those who like to imagine what atoms look like, some especially interesting chemical projects involve the construction of models of atoms and molecules. However, the real value of these projects depends on how well they help us understand, manage, or estimate what will happen during an invisible chemical reaction.

The raw materials of chemistry are found in many different forms in the earth's rocks, oceans, and air, and in the thousands of different kinds of plants and animals. But nature's often brightly colored and always carefully arranged crystals exceed all others in showing an orderly arrangement of atoms, **ions**, and molecules. It is certainly interesting to imagine watching the tiny particles of a substance leave a liquid in which they cannot stay and arrange themselves in precisely controlled patterns. Although we are limited to enjoying those things we can actually see, interesting and informative projects involve making one or another kind of a crystal and studying the arrangement of the particles that make the crystal appear as it does. The manner in which atoms, ions, or molecules arrange themselves in crystals also helps to prove how these particles are involved in chemical reactions.

Anything we can see, feel, hear, or taste when a chemical event occurs can be the purpose for another type of chemistry project. To associate a particular color change, for example, with the rearranging of a definite kind and number of atoms or molecules is to understand one of the fundamental purposes of chemistry. Even a simple burning candle becomes a challenge when we attempt to connect the color of the flame, the heat produced, the dripping of the candle wax, or the smoke of the flame to the rearranging of atoms and molecules. And who wants merely to be entertained by the whistling explosion we see and hear when a burning match is placed in the open end of a hydrogen-filled test tube?

Another large group of chemists is working to be certain that newly produced chemicals have the properties the manufacturer expects them to have. These "quality control" chemists invent methods to check the dye in cloth, the cleaning ability of a soap, or the killing power of an insect poison. Their work is even more interesting because they are also always seeking methods of improving products or suggesting better uses for their products. Interesting chemistry projects develop when we try to determine whether two samples of yellow dye that are used in the same way produce exactly the same color of yellow cloth. How important is the temperature of the dye **solution** in affecting the permanence of dyed cloth? What effect would be produced if there were a slight rearrangement of the atoms in the molecules of a yellow dye? If a yellow dye can be extracted from the roots of a special kind of tree, does this dye contain any of the same molecules as those in dyes that have been manufactured? Obviously, "control chemistry" suggests many excellent chemistry projects.

Learning as much as we can about a group of useful or interesting substances is another type of chemistry project. Consider those substances which cause fruits or vegetables to taste sour. The study of fruit and vegetable acids, where they can be found, how they can be extracted and made pure, how the peculiar characteristics of their molecules give them their special properties, illustrates this type of project. Another challenge involves how some of these substances might be produced in our laboratory rather than in orchards or fields. Projects involving occurrence, properties, preparation, and uses are excellent places to start. Very often, our developing knowledge of a group of chemicals shows us more challenging studies—for example, of some especially puzzling property of a substance, or of discovering an especially interesting use for it.

Another type of project involves learning as much as we can about a process or procedure that is important in many kinds of chemistry. **Polymerization**, for instance, is one of these processes.

Many of the very useful plastics and threads used in making cloth that have been created during recent years involve polymerization, the joining of many small molecules to form nets or chains of molecules, and then the use of these chains of molecules to make new and useful properties. Learning how to manage "poly" processes, or understanding more clearly what happens during polymerization, can produce better results than simply doing the projects. Polymerization processes illustrate how relatively simple experiments can become introductions to the rapidly growing different types of chemistry.

Often we are interested and curious about chemical events that occur in nature. The beauty of leaf colors on autumn trees, the lovely shapes of rocks in caves, the way the minerals in rocks redistribute themselves, reveal to us the kinds of things that can be projects in our study of nature's chemistry. If we notice the shapes and colors of things around us and, especially, the changes in the things we see every day, we will soon be eager to investigate one or more of nature's chemical events.

Obviously, exciting and challenging projects should not be limited to only one of the types described here. Most projects will combine several types of explorations, investigations, and experiments.

A Plan for Your Use

When a man works in science, he is often working alone. This is true of chemistry, as it is of any other science. The successful chemist must be able to plan and accomplish his experiments by being inventive and using imagination. There is no perfect plan for success in chemistry. But this does not mean that we cannot benefit from the experience of other successful chemists. We can consider what they have done and how they did it, and determine the pattern or plan they used. Their plan can serve as a guide for our own working methods.

At the start of the series of events that result in discoveries or inventions in chemistry, a man becomes curious about something someone has told him, or he has read about, or he has observed himself. Thus, one of the first things that must happen in starting a chemistry project is to become curious, very curious, about something and want to investigate and experiment with it. But experimentation must be aimed toward a definite purpose. For this reason, the sooner a person can understand what his project will be like and what his project will enable him to accomplish, the greater the probability that his project will be successful. The second thing to do in planning a project is to devise a clear statement of what one is trying to do.

The next step is to form a **hypothesis**. A hypothesis should begin with the word "if," and later use the word "then." This enables us to decide what we want to do and then plan to do it. *If* I do this, *then* that is likely to happen, be proved true or false, or help me plan more effectively than I can now. A good professional chemist will spend a lot of time thinking of promising **hypotheses**. Beginning chemists should develop this ability. Also, the manner in which hypotheses are stated can either help or delay progress in experimentation.

Just as a well-stated hypothesis leads to an experiment or investigation, a well-done experiment provides a solution to a problem or an answer to a question. The simplest kind of experiment consists of bringing together everything that we think is needed to cause something to happen, and then watching to discover whether what was predicted does happen. For example, a problem might be to grow a green crystal around a red crystal. The hypothesis might be: If a small red crystal is placed in a **saturated** solution of a salt that is known to form green crystals, then new layers of the green crystal will form around the red crystal. The experiment is conducted by simply placing a small red crystal in a saturated solution of the salt that forms the green crystals. If the green crystal layers appear, then you know that the hypothesis was correct. But if the red crystal begins to dissolve, then you know that you must change one or more features of your hypothesis and design a new experiment.

Equally simple in design is the kind of experiment in which we remove or omit the one thing that seems to be essential to cause the results in which we are interested. If this prevents what we thought it would from occurring, we can know that what was omitted must have an important part in causing the event.

A third kind of experiment is in increasing or decreasing the amount of something we think is important in what we are trying to do. If the results show a similar change in the event, we can be sure that we changed something that, at least partly, causes the event. For example, the problem might be to discover the reason for the low melting temperature of an **alloy**. The hypothesis might be: If the alloy contains bismuth, then it is the bismuth that lowers the melting temperature of the alloy. Thus, the experiment becomes: Compare the melting temperature of different quantities of the alloy containing different amounts of bismuth.

Doing an experiment and examining the results should complete a project. In many cases, however, other experiments must be done first, before we know how to proceed with the main experiment. It is important to continue to be curious and hopeful, although what we are attempting to do seems to be more and more difficult to achieve.

Chemists publish magazines and books in which their experiments and investigations are reported. Look for articles in the magazines about the subject of your experiment. Don't be discouraged, however, if you cannot find prepared solutions to your problem or exact descriptions of how to construct what you want to make. Often, the more difficult the problem, the less likely you will be to find answers already prepared. Books and magazines provide general information, but the excitement and enjoyment of exploration and discovery come only from investigations and experiments. Experiments and investigations, properly planned and carefully done, help most to make a chemistry project something to enjoy and be proud of.

2

EXTRACTING AND PURIFYING

Extracting and purifying is an important part of chemistry. Only very few kinds of atoms or molecules can be found in the earth's rocks and soil or its oceans and atmosphere in a pure state. Similarly, the substances that are produced by the life processes of plants and animals are usually combined and mingled. For some of our needs, this presents no problems. Blocks of stone can be used for building houses, and it does not matter that the stone may be composed of several different kinds of minerals. Similarly, whole grains of wheat can be ground to make flour for bread and whole pepper seeds can be ground to produce flavor for our food.

Many more of our needs require purified substances—that is, substances which have been extracted or separated from all of the other substances with which they are combined or mixed in nature. Iron only partly separated from the rocks where it is found would not make a very sharp knife, and salt mixed with all the other kinds of salt that are dissolved in ocean water would certainly add peculiar flavors to your food.

The plan or purpose of extracting-and-purifying chemistry is much easier to describe than to apply. The plan is to discover a characteristic property that distinguishes the substance we want to extract. Color, for example, is an easily characterized property. It allows us to select red apples easily from a basket containing apples of different colors. **Solubility,** the property of a substance that makes it dissolve, especially in water, is another easily recognized property. It would enable us to separate sugar from a sugar-and-sand mixture. But to extract the sugar from the sugar-water solution will need another property. To solve this problem, we apply our knowledge that water and sugar have different boiling temperatures. Thus, by boiling the water until there is no more, we will have the sugar separated from the original sand-sugar mixture.

Thus, the first thing to do in extracting and purifying in chemistry is to learn as much as possible about the properties of the substance we want to extract, and, similarly, of the substance with which it is combined or mixed. Don't forget the possibility that several property differences will have to be used, and that the extraction process will proceed in a series of actions. Also, extraction or separation procedures increase in difficulty as the properties of what we want to separate become similar to the properties of the substances with which it is combined. In these cases we must look for less obvious and often less easily managed differences in properties.

Fortunately, books are available which contain lists of the properties of many substances, properties that are especially useful in extraction and separation procedures. Two substances which differ in boiling temperatures, for example, can be separated by boiling away the substance that boils at the lowest temperature. Two substances that melt or freeze at different temperatures can be separated by heating them hot enough to melt the substance with the lower melting temperature, and then pouring it away from the other, solid substance. Differences in solubility have another advantage. Often it is possible to handle a mixture of several different substances in a manner that converts only the desired substance to a condition where it will not dissolve, thus permitting its separation by pouring off the liquid or filtering out the material that cannot be dissolved. We begin by trying to use the more manageable properties to extract or separate what we are seeking and then, if necessary, using the more complex properties.

The next thing to do in extracting and purifying is to try to understand why the substance we seek stays combined with other substances. If it is combined with the other substances by electrical forces, for example, other electrical forces may solve the extraction problem. Similarly, if atoms of the substance have been fastened to other kinds of atoms by extreme heat or pressure, it is obvious that much heat, or other kinds of energy, may be required to release the substance.

The plans for purifying are similar to those for extraction. Substances that are not wanted must be extracted until a substance that cannot be separated into two or more substances remains. This quantity of "pure" substance should be exactly like all other quantities of the same substance. If it boils at the same temperature, freezes at the same temperature, has the same weight, color, and other properties as those the books say it should have, then we can have confidence that our quantity of the substance is pure. However, if a "pure" quantity of a substance does not combine with other substances in experiments as it should, it is possible that it was not as pure as we thought it was.

Extracting and Purifying Flower Pigments

To extract and purify one or more of the substances that give flowers their colors can be a useful and interesting first experiment in purifying and extracting. Many of the skills which must be developed and practiced are used by professional chemists. And although flower pigments may have little or no sale value, any chemist can be proud of a small quantity of brightly colored pigment crystals, because of the careful and intelligent work required to produce them.

Flower pigments are delicate and can be easily destroyed. Using the wrong chemicals or procedures can destroy or alter the complex molecules we want to extract. Moreover, although we may have plenty of brightly colored flowers for our experiment, the amount of pigment in them is very small. Unless separation procedures are skillfully done, the small quantities of pigment may not be separated. But these difficulties apply to many of the things today's chemists are trying to extract and purify.

The procedures that follow are taken from a book by A. H. Halevy and S. Asen on the extraction and purification of pigments from tulips, a brightly blooming flower. These procedures may be used to extract similar pigments from other kinds of flowers, but new problems may arise, demanding clever efforts to solve them.

1. Collect as large a quantity of the flower petals, the colored portions of the flowers, as conveniently possible.

2. Dry. This will remove the major unwanted substance, which is water. For best results, the petals should be dried in an oven with air blowing through it at approximately 50 degrees **centigrade.** They could be dried in a laboratory oven without air blowing through it, or by allowing the sun, a lamp, or the heat in a room to accomplish the drying process. Too much bright light should be avoided, and the drying petals will spoil and become rotten if air does not blow freely through them. Women's stockings are suitable containers for collecting flower petals and storing them during the drying process.

3. Crush. This can be done with a **mortar and pestle** to crush the leaves to a fine powder. This procedure is necessary because the pigments are protected by the walls in the cells of the petals. Crushing helps to break through the walls of the cells.

4. Save approximately three-quarters of the

total amount of dried petals for use if an accident forces you to begin again, or in case you want to use what you have learned in trying to increase the amount of pigment you extract in a future experiment.

5. Extract in cold methanol containing 1 percent hydrochloric acid. To do this, place the crushed petals and sand in a large test tube. Press them in firmly. Add only as much of the liquid as is needed to cover the petals and sand. After 5 minutes, pour the liquid into another container. Add more liquid, and repeat this operation as long as there is any noticeable color in the liquid where it is poured off.

6. **Filter.** The extracted pigments should be in the hydrochloric acid-methanol solution.

7. Prepare a saturated solution of lead acetate. Add this solution in small quantities to the pigment solution until no more solid material forms in the bottom of the container. The lead ions will unite with the pigment molecules, and the pigments we want to extract are now mixed with the lead crystals in the bottom of the container. Separate these crystals from the liquid by filtering. Save the liquid in a properly marked container in case you need it again.

8. Wash the lead salts of the pigments with pure water, and allow it to dry.

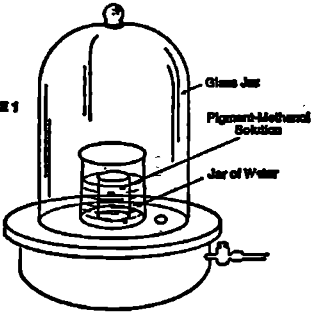
9. To remove the lead from the pigments, add a small quantity of methanol containing 2 percent hydrochloric acid. The lead ions will leave the pigment molecules, unite with the chloride ions, and form solid material (lead chloride) in the

bottom of the test tube. The pigments will be in solution in the methanol. Remove the lead chloride by filtering.

10. If a small amount of lead remains combined with the pigment molecules, bubble hydrogen sulfide gas through the mixture. This helps **precipitation.** Remove the lead by filtering.

11. The pigments are concentrated by allowing about 80 percent of the methanol to **evaporate.** This can best be done under **vacuum,** as shown in Figure 1, or by heating to 40 degrees centigrade in open wide-mouthed containers. Methanol vapors burn easily; *do not expose them to open flames or a serious fire may result.*

FIGURE 1



12. Cool concentrated pigment solution below room temperature and remove pigments by adding ether in small quantities until precipitation is complete. WARNING: *Ether can easily explode. Have no flames in the room when using ether.* Pigments are not easily **soluble** in ether. Filter to recover the pigments.

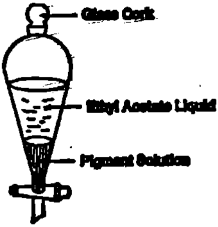
13. Redissolve the pigments in a small amount of methanol containing 1 percent hydrochloric acid and store for 3 days at approximately 4 degrees centigrade. If there are any other substances in the solution, they will precipitate during storage.

14. Filter to remove the **precipitate.**

15. Again evaporate the methanol as in Number 11.

16. Again dissolve the solids in a small amount of 1 percent water solution of hydrochloric acid. Add at least an equal volume of ethyl acetate to the water solution and shake together well in a closed container. The ethyl acetate will not dissolve in the water, but will float on top of it as a separate layer. The impurities in the pigments we want will dissolve in the ethyl acetate. A total of four washings are made. This can be done very easily by using a device called a separatory funnel as illustrated in Figure 2. CAUTION: *When shaking these two liquids together, it is necessary to open the container occasionally to prevent explosion of the container by vapors formed during washing.*

FIGURE 2



17. Place the purified pigment solution in small glass dishes. Allow the liquid to evaporate in a place where there is no dust in the air. As the liquid dries, the crystals of the extracted and purified pigment should appear. If there are no crystals, however, and after the liquid evaporates a thick liquid material is left in the dish, it is probable that the crystals of the pigment are not pure. Remember what you have done during the experiment, and repeat those parts of the process that you believe will assist in the purification process. For example, Number 9 might be an excellent place to start repeating the process of purifying the pigments.

Extraction of Vegetable Oils

When chemistry was merely beginning to be a science, the extracting of substances from the bark, leaves, roots, and other parts of plants was the principal work of chemists. Plant extracts were used by many people for medicines, dyes, drinks, and other purposes. Now there is much more emphasis on extracting or making substances from oil, coal, and other raw materials. But there are enough very important substances still obtained from plant sources so that this kind of chemistry is worth studying. Sugar, vegetable oils, medicines, and expensive perfumes are some of these substances. To extract the oil that gives sassafras its pleasant and interesting odor will help beginning chemists understand the plans and procedures of extraction chemistry. The sassafras tree grows in many parts of the United States. Stores also often sell sassafras root bark.

The roots should be washed carefully, and the bark of the roots cut into small pieces. As soon as the experimenter begins to cut the bark of the roots, he knows that the substance to be extracted is in the raw material because he can smell it. The problem is to learn how to extract it.

Sassafras oil is more easily dissolved in steam than in hot water. Perhaps we can put steam into the chopped root bark and then allow the steam to cool and become liquid, hoping that the oil will separate from the hot water. Figure 3 shows a device that will do this.

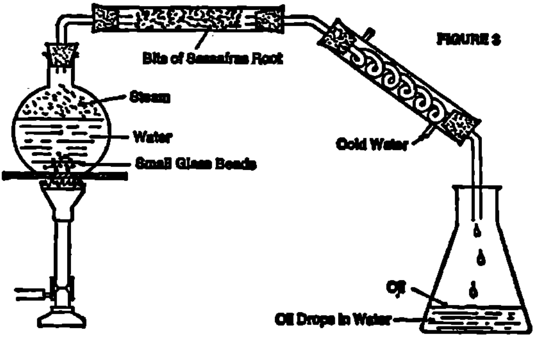


FIGURE 3

The oil collects in drops near the bottom of the flask, but some of the oil may come to the surface of the water. The next problem is to separate the oil from the water. One method of doing this is to use a small glass tube. By sucking on the end of the tube, the oil can be taken into the tube without the water. If the oil is then put into a separatory funnel, the separating of the oil from the water is easy.

One of the best books telling about sassafras oil and similar kinds of oils is *The Essential Oils*, written by Ernest Guenther. Guenther says that sassafras oil is 80 percent safrole, 10 percent alpha-pinene and phellandrene, 6.8 percent *d*-camphor, and 0.5 percent eugenol. Sassafras oil containing 80 percent safrole will become a solid at 4.6 degrees centigrade. For each 10 percent less safrole, the temperature will be reduced 3 degrees. Thus, sassafras oil with 70 percent safrole will become solid at 1.6 degrees centigrade. For this reason, the temperature at which sassafras oil becomes solid is a measure of its purity. Guenther suggests: Put about 10 **cubic centimeters** (cc) of the oil in a dry test tube. Cool it in water or a suitable freezing mixture, the temperature of which should be 5 degrees less than the temperature at which the oil is expected to become solid. To help the oil become solid, rub the inside of the test tube with a glass rod or add a small amount of sassafras oil that has been made solid by cooling it. The rubbing of the glass rod helps to remove the heat in the oil. The temperature should be measured frequently. The temperature will increase rapidly at the start of this process, then it will change very slowly or not change at all. This is the temperature at which the oil becomes a solid. Before the oil is tested, a small amount of sodium sulfate should be added to it. The sodium sulfate removes the water in the oil. If the water is not removed from the oil, the temperature at which it becomes solid is much lower.

The Extraction and Purifying of Sodium Chloride

The ceaseless moving and changing of the surface of the earth have caused some of the water of the oceans to sink into the earth. As a result, the salts that were in the sea water have collected in many places under the earth's surface, forming what is called rock salt. To extract sodium chloride, the salt used to flavor food, from this raw material is an especially challenging chemistry project. This is because the raw material will contain nearly every element and compound that can be dissolved in water.

After the rock salt is dissolved in pure water, many of the unwanted elements and compounds can be removed by filtering. Further purifying, however, uses a different plan. By adding a saturated calcium hydroxide solution to the hot rock salt solution, for example, any magnesium, iron, or aluminum ions in the salt solution will sink to the bottom of the container. Bicarbonate ions become calcium bicarbonate and will also sink. To remove the calcium and barium ions remaining in the salt solution, add a quantity of anhydrous sodium carbonate.

To remove the sodium carbonate remaining in the solution requires a different plan. The carbonate ions in the solution can be changed to water and carbon dioxide by the action of hydrochloric acid.

3

ANALYSIS—DISCOVERING WHAT KIND AND HOW MUCH

One of the most important things chemists do is discover the kinds and quantities of elements or compounds in a substance. This work is called chemical analysis. The work of **analytical** chemists can be major projects, such as determining how much iron there is in a railroad car loaded with iron ore. Or analytical chemists can try to determine how much gold there is in a 1-ounce stone that is known to contain gold. One chemist may need to determine the amount of a special medicine that can be extracted from thousands of gallons of the liquid that is the raw material for the medicine. Another chemist may try to discover whether there is a tiny amount of arsenic in a few hairs of a murder victim.

Analytical chemists occupy important positions in many industries, professions, and laboratories. How much a railroad train loaded with iron ore is worth depends on how much iron can be extracted from the ore. It would be impossible to discover the best methods of producing a certain medicine if it were not possible to compare how much medicine could be made using different conditions for producing it. And what physician would be willing to give medicine to a patient if he were not sure the man who made the medicine knew what substances he was putting into it? Knowing the kinds and amounts of substances used in any rearranging of atoms and molecules is the first thing necessary in managing or explaining the things that happen when the rearranging occurs.

The general plan of chemical analysis begins with establishing a set of properties or characteristics of an element or compound that uniquely identify it. Actually, no chemist can know the special properties of all the elements and compounds which occur. The earth's rocks, its oceans and atmosphere contain many, many substances. It is true that there are less than one hundred elements in nature, but there are millions of compounds, especially when we consider the complex compounds that make one animal or plant different from another. For these reasons, a chemist can seldom start an analysis problem by asking: What elements or compounds are in this substance? Usually, he must ask: Is there any iron in this substance and, if so, how much? Or: Is there an **enzyme** in this plant extract? If so, which enzyme and in what quantity? Thus, an analysis type of chemistry project can best be started by guessing what kinds of elements or compounds are in the substance you are investigating, and then selecting the properties that will prove whether these elements or compounds are present.

The next part of the plan is discovering a method of causing these elements or compounds, if present, to reveal the properties that will show they are there. Often the substance is treated in a manner that causes one or a few compounds to change while other compounds are unchanged. In other cases, the unknown substance is used as if it were raw material and treated in such a manner that if the element guessed to be present is actually in the substance, it will be changed to another substance that is easy to recognize. It is probable that the new substance would not have appeared if the other element or compound guessed to be there had not been present.

Deciding the Presence or Absence of Chemical Elements in Small Quantities of Material

Chemists, particularly Fritz Feigl of the University of Brazil, have developed reactions that produce distinctive colors or other results that can be seen for many of the elements. Many of the methods require such small amounts of material that they can be accomplished in a small hollow in the surface of a piece of glass or in spots on filter paper. These "spot" tests are so exact that the tiniest amount of an element can be found in the solution thought to contain the element.

Using small quantities of **reagents** and answering so many "What kind?" questions, these spot tests are very interesting for beginning chemists. If the chemist is careful to ensure that all his equipment is clean, and if he does as the instructions say he should, he can become experienced and answer questions such as: Does unwashed fruit contain arsenic that was put on it to kill insects? Are the holes in a piece of cloth actually made by gun shots? Does this "gold" ring actually contain gold?

To gain confidence in your ability to use these spot tests, it is wise to prepare solutions containing very small quantities of the element being tested for, and prove that these "test" solutions contain the element. For example, while practicing the test for aluminum, prepare a small quantity of 0.5 M aluminum solution. This solution will contain approximately 1 aluminum ion for each 100 water molecules. By mixing 1 cubic centimeter of this solution with 9 cubic centimeters of water, the solution can be changed to 1 ion of aluminum for each 1,000 molecules of water. Similar mixing of solution and water can reduce the amount of aluminum to water to 1:10,000; 1:100,000, and 1:1,000,000. Any test that is supposed to prove the presence of aluminum in these "test" solutions and fails to do so should inform the chemist that he is doing something wrong, or that he is expecting the test to be more exact than it can be. Remember, also, that a test can be relied upon only when it is conducted under prescribed conditions, and with a test solution containing no other substances that might change the results. Few beginning chemists will be willing merely to do these tests as they are explained in this book. You will probably want to examine the kinds of reactions that occur and why they occur. Feigl's books will be very helpful in this.

Unless otherwise specified, each of the experiments described in this chapter can be done either on a small hollow in a flat piece of glass or as spots on filter paper.

a) Aluminum. If the solution is not certainly alkali, add enough ammonia water to be certain it is alkaline. To a drop of the test solution, add a drop of 0.1 percent alizarin S. Add drops of 1 N acetic acid until the violet color disappears, then add one more drop. The red color which slowly appears indicates that there is aluminum in the test solution. PROBLEM: Do acid fruit juices pick up aluminum on standing in an aluminum container?

b) Arsenic. Mix a drop of the test solution in a small crucible with a drop or two of ammonia water, a drop of 10 percent hydrogen peroxide, and a drop of 10 percent magnesium chloride solution. Evaporate slowly, then heat. Add to what is left in the crucible a drop or two of stannous chloride solution in 12 M hydrochloric acid and warm this solution. The appearance of a brown-black color indicates that arsenic is present. PROBLEM: Is lead the only metal shot from guns?

c) Barium. Prepare reagent paper by soaking filter-paper strips in sodium sulfate solution and drying. Mix 3 drops of the test solution with a drop of saturated potassium permanganate solution in a small crucible. The mixture will be violet. Place a drop of the violet liquid on a strip of the reagent paper. Place the paper in an oven and heat it for 7 to 10 minutes at 70 to 80 degrees centigrade. As soon as the paper becomes brown, soak it in a solution of sulfurous acid until it becomes white. If barium was present in the solution, violet spots or rings will appear where the test solution was placed on the paper. PROBLEM: Are barium compounds used in the material used on fires to cause colored flames?

d) Bismuth. Prepare a small quantity of reagent solution. To do this, put 5 grams of stannous chloride in 5 cc of 12 M hydrochloric acid and add water to make 100 cc of solution. Mix this with the same amount of 25 percent sodium hydroxide solution. On a small piece of glass mix 1 drop of the test solution, a drop of saturated solution of lead chloride, and 2 drops of the reagent. If there is bismuth present, a brown color will appear within 3 minutes. PROBLEM: If a medicine has the word "bismuth" in its name, does it actually contain bismuth?

e) Calcium. Mix a drop of the test solution with a few drops of concentrated ammonium ferrocyanide solution. Mix with a drop of alcohol. If crystals appear, or if the mixture is not clear, calcium is present. PROBLEM: Is some of the calcium in milk present in the liquid part of sour milk?

f) Chromium. Make a small ring in the end of a piece of platinum wire. Dip this into a drop of the test solution. Evaporate to dryness over a small flame. Then heat the ring until it is red and dip it into a mixture of one-half sodium potassium carbonate and one-half sodium peroxide. Reheat and repeat the dipping process until a glassy bead forms on the ring of wire. After the bead is cold, dissolve it in 1 or 2 drops of 1:1 sulfuric acid. Add 2 drops of a 1-percent alcoholic solution of diphenylcarbazide solution. A violet color indicates the presence of chromium. PROBLEM: If a chromium-covered part of an automobile is allowed to stay for many days in a solution of sodium or calcium chloride, which would be approximately the same as the effects of salt solutions used on highways in the winter, will the salt solution then acquire a small amount of chromium?

g) Copper. Place a drop of the test solution and a drop of pure water near each other on a piece of glass. Add and mix to each of these a drop of ferric thiocyanate solution and 3 drops of 0.1 N sodium thiosulfate solution. If there is no copper in a solution, the color disappears in 1 to 2 minutes. If there is copper present, the color disappears immediately. To prepare the ferric thiocyanate solution, dissolve 1.5 grams of ferric chloride and 2 grams of potassium thiocyanate in 100 cc of water. PROBLEM: Is it possible to prove that copper is present in a very small bit of metal from a "silver" or "gold" piece of jewelry?

h) Gold. Dissolve in aqua regia the metal thought to contain gold. This may be done by putting a few bits of the metal into 1 drop of nitric acid to which has been added 3 or 4 drops of hydrochloric acid. If the gold is already in the form of a soluble salt, prepare a few drops of the salt solution. Suck a drop of the test solution into a very small glass tube. Slowly evaporate the solution so that the solids from the solution are left near the end of the glass tube. Heat the end of the tube until a ball of melted glass is formed on the end of the tube (see Figure 4).

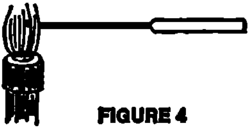


FIGURE 4

Hopefully, any gold present is converted to metal particles in the ball of glass, and should be visible. PROBLEM: Does the material used to print names on leather or plastic actually consist of a thin sheet of pure gold?

i) Iron. Place a drop of the test solution on a filter paper or a piece of glass. Add a drop of potassium ferrocyanide solution. A blue color indicates iron. This test can also be made by repeating the same procedure, but using a drop of 1 percent potassium thiocyanate solution instead of potassium ferrocyanide. In this test, a red color indicates iron. PROBLEM: Can iron compounds be soaked from red or yellow clay or sand by hydrochloric acid?

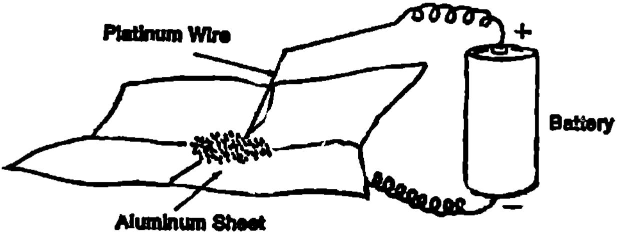
j) Lead. A drop of the solution is placed on filter paper. As soon as the liquid disappears; add a drop of 0.2 percent solution of sodium rhodizonate. A blue spot or ring appears if lead is present. If the blue color is very bright, another process can prove there is iron present. Add a drop of a solution containing 1.9 grams of sodium bitartrate and 1.5 grams of tartaric acid dissolved in 100 cc of water. The blue color then becomes bright red. PROBLEM: If water stays for severals days in a lead pipe and then is boiled until there is only a little remaining, does the water contain dissolved lead?

k) Magnesium. Add a very small drop of 1 N potassium hydroxide and hydrochloric acid to the test solution if necessary to be certain that the test solution is slightly acid. Mix a drop of the test solution and a very small drop of iodine solution. If the solution is not brown, add more iodine solution. Add more potassium hydroxide solution until the test solution is yellow. Brown particles in it indicate magnesium. PROBLEM: Is magnesium partly the cause of water marks left in a basin after the water is removed?

l) Manganese. Prepare a silver ammine salt solution by adding ammonia to 10 cc of saturated silver nitrate solution until the solids that form in the bottom of the flask are dissolved. Then add an equal amount of ammonia. Place a drop of this liquid on filter paper and add a drop of the test solution. If there is manganese present, a black spot will appear, which becomes blacker when warmed. PROBLEM: Is a substance containing manganese used in electric batteries?

m) Mercury. The test solution should be neither acid nor alkali. Place a drop of the test solution in the hollow of a thin sheet of aluminum that has been scraped so that it has a roughened surface. Add a drop of sodium sulfate solution and a drop of quinone solution. Place the end of a platinum wire in this solution. Connect the platinum wire to the + end of a battery (Figure 5). Connect another wire between the thin sheet of aluminum and the − end of the battery. After 15 minutes, remove the wires and wash and dry the aluminum sheet. Five minutes later, dampen the place where the test solution was with an acetic acid solution of alizarin. Wait 3 minutes. Wash with water, and dry with a clean cloth. Add another drop of the alizarin solution, wait 3 minutes, and wash with pure water 10 times. If mercury is present, red spots will be seen on the sheet of aluminum. PROBLEM: If a medicine is supposed to contain mercury, can the presence of mercury in the medicine be proved?

FIGURE 5



n) Molybdenum. Moisten a spot on filter paper with 1:1 hydrochloric acid. Add a drop of the test solution and a drop of 10 percent potassium thiocyanate solution. A red spot will appear if iron is present. Remove the iron-red spot with a drop or two of 5 percent stannous chloride in 3 N hydrochloric acid. If molybdenum is present, a dark-red spot will appear. PROBLEM: Is molybdenum used to harden the steel for knives?

o) Nickel. Place a drop of the test solution and a drop of 1 percent dimethylgloyoxime solution on filter paper. Place the filter paper over the top of a flask of ammonia. A red spot or circle indicates nickel. If it is possible that other metals are present —iron, cobalt, or copper, for example—prepare a 1 percent alcoholic solution of rubeanic acid. Place a drop of this reagent on the spot produced by the previous procedure. A blue ring appearing outside the other colored rings indicates nickel. PROBLEM: Can this test be used to prove nickel to be present in only a few particles of an alloy known to contain nickel?

p) Silver. Place a drop of 0.1 N hydrochloric acid on filter paper and add a drop of the test solution. Add another drop of the acid and a drop of 0.1 N manganese nitrate and a drop of 0.1 sodium hydroxide. Blackening of the spot indicates silver. If mercury or lead is present to make this test less positive, the fact that silver salts can be changed by light can be used for another test. In a small circle on filter paper, put a drop of the test solution. After 2 or 3 minutes, place the paper in 0.02 N potassium bromide for one-half minute. Replace the potassium bromide with pure water. Stir the water, then remove it and add more water. Do this several times. Remove the water. Soak the filter paper in pyro, which is a solution used in preparing photographs. A gray spot of silver where the spot of test solution was placed indicates silver. PROBLEM: Is there silver in photographs? Does the amount of silver depend on how dark the photograph is?

q) Strontium. Place a drop of the test solution on filter paper that has been soaked in potassium chromate solution and dried. Add a drop of 0.2 percent sodium rhodizonate solution. A brown-red spot or circle indicates strontium. PROBLEM: Do yellow-colored rocks always contain uranium?

r) Tin. Soak filter paper in 5 percent water solution of phosphomolybdic acid. Hold the paper over an open bottle of ammonia until it becomes yellow. Dry the paper and store it in a dark bottle with a cork in the top. Place a drop of the test solution on a piece of this paper. A blue color indicates tin. Another interesting test involves the coloring of flames by tin compounds. Place hydrochloric acid in a glass dish and add some of the test solution. Add a few bits of pure zinc. Stir with a test tube that contains cold water. Place the bottom end of the test tube in a colorless flame. A blue flame indicates tin. PROBLEM: Can these tests be used to determine whether a sheet of metal is made of tin?

s) Titanium. If necessary, add hydrochloric acid to the solution to be certain it is acid. To a drop of the test solution add 3 or 4 drops of 0.025 percent methylene blue solution and a tiny particle of zinc. Prepare a similar solution in which there is no drop of the test solution. Compare the number of minutes required for the solutions to lose their color. If the color disappears quickly, titanium is present. PROBLEM: If a white paint pigment does not change color in hydrogen sulfide vapor, could it be that this pigment is a compound of titanium?

t) Tungsten. Mix 1 or 2 drops of the test solution with 3 or 4 drops of stannous chloride. A blue color indicates tungsten. Another test involves adding hydrochloric acid to make certain the test solution is neither acid nor neutral. To a drop of this solution, add a very small drop of 1 percent titanous chloride and a very small drop of 0.005 percent water solution of malachite green. Loss of color indicates tungsten. PROBLEM: When an electric lamp stops giving light, it often becomes black. Is this black caused by tungsten on the inside of the lamp?

u) Uranium. Place a drop of potassium iodide solution on filter paper. In a minute or two, add a drop of the test solution. Add a drop of potassium iodide solution, followed by a drop of sodium thiosulfate. Add a drop of potassium ferrocyanide. A brown or yellowish circle indicates uranium. Another proof is the appearance of red color when a drop of 0.12 percent fluorescein solution and 3 drops of 5 percent ammonium chloride are added to a drop of the fluorescein solution. PROBLEM: If a rock seems to be **radioactive,** is it because there is uranium present?

v) Vanadium. Mix a drop of 20 percent sulfuric acid solution with a drop of the test solution on a piece of glass. After a few minutes, add a drop of 1 percent hydrogen peroxide solution. Add another drop after a few minutes. The appearance of red or pink color indicates vanadium., PROBLEM: Can vanadium be found in a few particles of metal taken from a tool that is supposed to be very strong?

w) Zinc. To a drop of the test solution add a drop of resorcinol in alcohol and a drop of 6 N ammonia. A blue color indicates zinc. PROBLEM: Is the metal case of a battery manufactured from a zinc alloy?

Locating Impurities in Metals by the Imprint Method

The plan is to prepare a sheet of paper with reagents in it, and then place this paper on a smooth surface of the metal being studied. If the impurities are present, atoms of these substances will leave the metal and react with the reagents in the paper. Usually, the paper is covered with a thin layer of **gelatin** in which the reagents are present.

a) To discover whether there are phosphorus crystals in iron or steel. Be certain there is a flat surface on the iron or steel object to be tested. Dip a sheet of filter paper in nitric acid-ammonium molybdate solution, drain briefly, and place the paper on a piece of glass. Place the metal object on the moist paper and leave it there 3 to 5 minutes. Remove the metal object and place the paper in a solution of stannous chloride. This solution is prepared by adding 5 cc saturated stannous chloride solution to 5 cc hydrochloric acid and 10 cc of water. Blue colors will appear if there is phosphorus in the metal. To be certain the color does not disappear, wash the paper in water which contains a small amount of alum.

b) To discover whether there are copper crystals in metal. Be certain there is a flat surface on the metal to be tested. Place a thin layer of hot **agar-agar** on a piece of filter paper. Dry. Dip this paper in 2.5 ammonia solution and place the paper on the flat surface of the metal. After 4 or 5 minutes, remove the paper and place it in rubeanic acid reagent. Move it while it is in the reagent until the print of the metal can be seen. To prepare the reagent, dissolve 0.5 grams of rubeanic acid in 100 cc alcohol. Mix 5 cc of this solution with 100 cc of water.

Electric Analysis of Rocks

To determine what kinds of elements or compounds are present in rocks or minerals is an interesting problem for chemists, especially beginning chemists. R. Jirkovsky has invented a procedure that helps to solve this problem. His equipment consists of flat pieces of copper and aluminum arranged so that electricity can go through them. Obviously, this procedure can be used only when the mineral being tested is of the kind that will allow electricity to go through it. In the arrangement, a sheet of filter paper moistened with potassium chloride solution is placed on the aluminum. Another sheet of paper that has been moistened with the proper reagent is the next layer. The flat piece of mineral (which has been cut and polished to form a thin sheet) is placed on the paper, and the copper is placed on the mineral. A dry-cell battery is connected to the top and bottom plates, as shown in Figure 6.

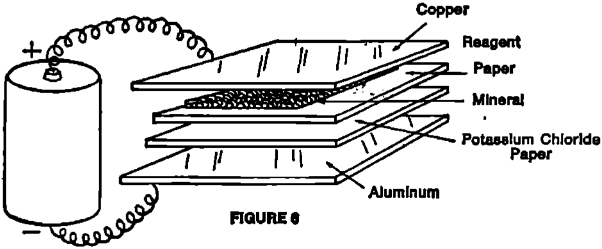


FIGURE 6

Practice the procedure using minerals whose composition you know. Also, practice the other procedures that have been described in this chapter to test for elements likely to be in the mineral. Iron can be proved to be in pyrites and other ores that have iron in them by using ferrocyanide paper. Lead or iron in sulfide ores can be proved to be present in the minerals by the yellow or blue spots which appear on chromate or ferrocyanide paper. Nickel reacts with dimethylglyoxime paper, cobalt with potassium nitrite and potassium thiocyanate paper, and arsenic with silver nitrate paper. Cadmium and antimony react with hydrogen sulfide paper, aluminum with alizarin paper, and bismuth with potassium iodide paper. Copper and zinc give characteristic colors with ferrocyanide paper.

4

MAKING NEW SUBSTANCES FROM OLD

We are surrounded today by many kinds of new plastics, wonderful new materials, metals, soaps, medicines, foods, and chemicals. It is difficult to recall those days in human history when mankind relied entirely on nature's unchanged materials to solve the problems of existence. The Stone, Bronze, and Iron Ages are all in the distant past. Today mankind uses such large quantities of so many different kinds of materials that it is difficult to find an appropriate symbol for modern living.

Converting substances with one group of properties to new substances with different properties is one of the oldest kinds of chemistry. Who knows when a new substance, hard and shiny in the ashes of a cooking fire, was seen by the first metalworker? Or how long ago it was when women noticed that certain clays or plant materials could be combined to make them look beautiful? Some of the methods for making substances used by our modern chemists have been used for centuries.

Thus, chemistry projects in which we attempt to convert substances to new and, we hope, more useful or interesting substances introduce us to one of the oldest and also the most useful types of chemistry.

Assuming we know what kinds of properties we want a new substance to have, how do we decide what raw materials to use and how to treat them so they will produce the substance we want? To say it in other words, how do we rearrange the molecules and atoms to form the compounds with the desired properties? This is probably one of the most puzzling questions of chemistry. Consider common table salt, for example. It is composed of two elements, chlorine and sodium. Many sodium atoms appear in a soft, easily changed metal that explodes in water. Chlorine as an element is a pale yellow-green gas. A small amount of chlorine can cause a person to choke. A great quantity of this gas can kill him. But combine sodium and chlorine ions and we have white crystals that people need to flavor their food.

A chemist must think and plan carefully in converting raw materials to new substances. For example, we know that potassium is similar to sodium and that bromine is much like chlorine. It seems likely that the combining of potassium and bromine will produce a substance that will resemble sodium chloride. This is correct. Considering this, the first part of our plan for changing old materials into new substances is to learn as much as we can about how to prepare substances that have properties similar to those of the substances we hope to produce.

The next part of the plan is to study the conditions involved in the production of substances like the one we hope to produce. Obviously, the properties of a substance depend not only on the raw materials but also on the amount of heat used, whether electricity is involved, and other factors, such as timing, mixing, pressure, etc.

The third part of the plan encourages us to learn as much as we can about how the separate atoms are held together in substances resembling the substances we hope to produce. When we plan to rearrange atoms, or change them from one molecule to another, success depends upon breaking certain connections between atoms and encouraging them to form new and different connections. Thus, beginning chemists must imagine how atoms are constructed and how they are fastened to other atoms. Fortunately, many experiments reveal the delight and joy, as well as the disappointments, which occur in seeing new substances with new properties appear. Many people begin their experiments in chemistry by trying and failing until a successful method is discovered. Finally, through experience, they fail less frequently and their successes increase.

Alloys

Two or more metals can often be melted together to produce a new material that has properties very different from those of either of the metals from which it was made. For example, spoons can be made from an alloy of bismuth, tin, and lead that will melt when it is placed in hot water.

A simple furnace can be constructed (see Figure

7) which, by producing temperatures hotter than 2,000 degrees Fahrenheit, solves one of the problems of preparing or examining alloys.

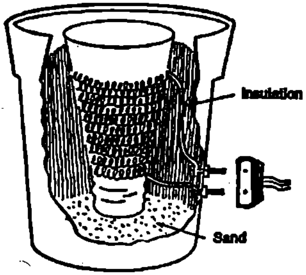


FIGURE 7

Put sand in the bottom of a flowerpot. Place an electric heating device in the flowerpot. The wires for the heating device are attached to bolts on the side of the flowerpot. An ordinary electrical device in the home can be used to cover the bolts and provide electricity. As much **asbestos** or mica **insulation** as possible is placed around the heating device inside the flowerpot. The top of the insulation is covered with small boards made of asbestos or furnace insulation. If the insulation is placed in the flowerpot carefully, this furnace will be excellent to be used again for experiments with alloys.

Temperatures in the furnace can be estimated by pyrometric cones. These form a device designed for measuring extreme heat in ovens used to bake clay products. Pyrometric cones are manufactured to melt at definite temperatures. If you cannot obtain them, purchase a chemistry book dealing with the composition and physical properties of alloys. You can measure the temperature of your furnace by discovering which alloys will melt in your furnace. WARNING: *The electricity used in this furnace and the high temperatures are both dangerous. Be sure your eyes are properly protected with safety glasses when experimenting with melted alloys.*

The Preparation of Pigments

Paintings on the walls of caves done 50,000 years ago are evidence that some substances retain their colors almost permanently. Most of these substances were dug from the ground but, as civilization advanced, painters learned how to extract equally brilliant and permanent pigments from plant and animal materials. When chemistry was still a young science, brightly colored salts and other chemical materials which were in the flasks and test tubes of chemists were taken by painters and used for their paintings.

There are several steps involved in the chemical preparation of pigments. First, reacting substances must be identified which, when they react, will produce a substance that will neither fade as time passes nor be washed off by water too easily. Second, these reacting substances must be brought together in a way that will produce as much of the desired pigment as possible. This is usually done in some kind of solution. Third, the pigment must be separated from the solution and other substances remaining from the reaction. Fouth, the purified pigment must be dried, made into powder, and filtered through a wire screen to be certain all particles of the pigment are the same size. A fifth step, for which the painter is usually more responsible than the chemist, involves mixing the pigment with oil to form the thick pastes the painter needs for his work.

Oil made from flax seed (flax is the plant from which linen is made) is the oil usually used for mixing pigments to make paint. The purpose of the oil is to hold the pigment particles together to form a thin layer. The oil used must cover each pigment particle, fill the space between particles, and be easy for the painters to use in their work. Obviously, the oil must have no color nor develop any color as it ages.

The experiments explained here begin with some pigments which are easy to prepare. Become experienced with these, and then experiment with the more complex pigments.

a) Iron blue. This dark-blue pigment is usually made by collecting the solids that form when ferrous and ferricyanide ions are brought together. The reagents used are usually ferrous sulfate and potassium or sodium ferricyanide.

b) Venetian red. This pigment is pure anhydrous iron oxide. It is produced by heating ferrous sulfate.

c) Chrome yellow. Chrome yellow is lead chromate. Mixing lead acetate or nitrate with sodium dichromate produces lead chromate as a solid. Chrome yellow is too bright for many painters, and they often make it less bright by mixing it with zinc white.

d) Ivory black. Ivory or bone black is produced by heating bones in a vacuum. Almost any kind of clean bones can be used. Actually, many beginners prefer to use the ivory black that can be bought in stores, but it also is interesting to prepare your own. The part remaining after the odor ceases to come from the heated bones is about 15 percent carbon and 85 percent calcium phosphate. When this material is made into a powder, washed, and dried, it can be mixed with oil to make the ivory-black pigment.

Preparation of Viscose

Viscose is imitation silk.

1. Soak a quantity of cotton in 18 percent caustic soda for an hour or two. Press the cotton to rid it of the extra alkali.

2. When dry, break it into small pieces and allow it to dry in the air for 2 or 3 days. It is now a kind of material called **cellulose.**

3. Convert it into cellulose xanthate. This is done by placing it in a bottle with carbon disulfide. The bottle should be attached to a machine that will turn it slowly at a rate of about 10 turns a minute. This should continue for 24 hours.

4. When the reaction is complete, there will be no threads of unchanged cellulose. Add 0.25 percent caustic soda until the mixture contains about 8 percent cellulose. Return the mixture to the bottle and allow it to turn slowly for another day. Then allow the bottle to remain still for 4 or 5 hours.

5. The newly formed viscose can be wound into threads by forcing it through the hole in a small glass tube. The hole in the glass tube should not be larger than 1 millimeter. Air pressure will be needed for this. One source of pressure is the water pressure in your house's water system. Another source is a large bottle fitted with a cork that has two holes in it, which will deliver air under pressure if water is allowed to enter the bottle. WARNING: *Working with air pressure can be dangerous: be careful.*

6. The viscose, as it comes from the glass tube, should enter a bowl of liquid consisting of 8.5 percent sulfuric acid and 15 percent sodium sulfate. The thread can be wound around a glass bottle, dipped into a solution consisting of water with a small amount of sodium sulfide added, and dried.

5

"SEEING" ATOMS IN MOLECULES

A man who directs the players in a game or sport cannot do much to help his team win if he cannot see his players. Neither can a chemist do much to control or manage a chemical reaction unless he can "see" the atoms he hopes will be rearranged from one molecule to another. But there is no device known that will enable him actually to see his very small "players." This is why chemists must imagine what atoms and molecules are like.

Sometimes chemists use their hands to convert what their mind imagines into models their eyes can see. Such visible models can help the chemist imagine what atoms and molecules really are and how they react when they contact millions of other atoms and molecules during chemical reactions.

To construct models of atoms and molecules, we must rely on the ideas and theories about their structure and behavior that other chemists have developed. One very valuable idea is to express the comparative weights of the atoms in easily used numbers. Atomic weight lists inform us, for example, that 1 oxygen atom is as heavy as 16 hydrogen atoms and that 1 gold atom is as heavy as 197 hydrogen atoms. It has been determined that there are approximately 600,000,000,000,000,000,000,000 (6×10^{23}) atoms in a gram of hydrogen. This number is called the Avogadro number. It is named for the scientist who discovered it. Because we know this number, it is possible, using mathematics, to figure the weight of 1 hydrogen atom. Because it is possibles to determine the weight of one kind of atom, it is possible to calculate the weight of all atoms. And because it is possible to measure a piece of the substance and figure its volume, or the space it occupies, the volume or size of single atoms can also be derived. To understand why this is so, remember that sulfur atoms are 32 times as heavy as hydrogen atoms. Therefore, 32 grams of sulfur will contain as many atoms of sulfur as there are atoms of hydrogen in 1 gram of hydrogen. By remembering how many atoms there are in 1 gram of hydrogen, we can figure how many atoms there are in our 32-gram piece of sulfur. This amount of sulfur occupies approximately 16 **milliliters**; therefore the size of a single sulfur atom is 16 milliliters divided by 600,000,000,000,000,000,000,000.

Unfortunately, few people can really understand or appreciate numbers that are so long. You may want to do some calculating to help you realize how large or small such numbers are. Measure how wide a small coin is, for example. Figure how wide a line of these coins could be made between the sun and the earth if you had as many coins as there are atoms in a gram of hydrogen.

Another useful item of information is that if two different gases at the same pressure and temperature are pumped into two containers of equal volume, there will be approximately the same number of molecules in each of the two containers. Each kind of gas molecule seems to require the same amount of space, regardless of the kind or weight of the molecules. Knowing this fact, it is easy to determine how many molecules of one gas react with one molecule of another gas. When equal amounts of the two gases are exploded or react with each other, then if two molecules of the first gas react with one molecule of the second gas, for example, one-half of the original amount of the second gas will be unchanged after the reaction is completed.

The plan for building visible models of invisible atoms or molecules is to extend what we can see or measure of large amounts of the substance and from this derive the size, shape, and weight of individual atoms or molecules. If crystals of a substance have long thin shapes, for example, then the individual atoms, ions, or molecules of the substance are likely to have long thin shapes.

Actually, chemists' ideas of the structure and arrangement of atoms has been developed using many different kinds of models that other men have imagined. One of the best methods of getting started on "seeing" atoms in molecules is to build models of the various different ideas that chemists have already developed.

"Counting" the Atoms in a Bit of Sulfur

Although it is easy to say that atoms and molecules are very tiny particles, their actual size is difficult to imagine. The problem expressed here shows how very small these particles are, and how extremely large the number is of particles present in any manageable quantity of material.

1. Using a mortar and pestle, make a gram of sulfur into a powder.

2. Place 0.32 grams of this powder on a sheet of smooth black paper. Remember that there are the same number of molecules of sulfur in 32 grams of sulfur as there are hydrogen molecules in 1 gram of hydrogen. Thus, the 0.32 grams of sulfur contain 6×10^{21} atoms of sulfur.

3. Make a smooth pile of the sulfur. With a knife blade, divide the sulfur into two piles that are as nearly equal as possible.

4. Divide one of these piles into two more equal piles.

5. Continue repeating the dividing procedure as many times as necessary to leave a small pile of sulfur in which you can actually count the individual bits of sulfur remaining. When finished, you should have a tiny bit of sulfur that can hardly be seen.

6. Knowing the number of times you have divided the pile of sulfur, and using the Avogadro number, figure the number of atoms in your almost invisible bit of sulfur.

7. Get a piece of sulfur weighing approximately

32 grams. Cut away portions of this piece of sulfur until it weighs *exactly* 32 grams.

8. Determine the volume of this piece of sulfur.

9. Use the Avogadro number to figure the volume occupied by each sulfur atom.

10. Assuming that each sulfur atom occupies a certain amount of space, figure the approximate distance between atomic centers of two sulfur atoms.

11. Obtain a large crystal of a mineral such as quartz, calcite, galena, or any other substance available. The purer the crystal, the better for this study.

12. Determine the weight and volume of the crystal.

13. Determine the amount of space, or volume, available for each molecule or group of ions in the crystal. Use the relationship between the Avogadro number and the molecular weight of the substance for this purpose.

14. Assuming that each molecule or ion group in the crystal occupies a certain space, figure the distance between molecular centers.

15. Assuming that the atoms in individual molecules or ion groups share the space the atom occupies equally, figure the distances between the atomic centers in a molecule or ion group.

16. Figure the distances between atomic centers of the element present in your crystal when they exist as pure elements. Decide whether the atoms in your crystal are closer or farther apart than they would be in their pure elements.

The methods and procedures used in this training problem can be used in estimating many kinds of atom-molecule shapes, sizes, and distances. For example, how many sodium and chloride ion pairs are there in a grain of table salt? How far apart are the molecules in a grain of sugar?

The Relative Weight of Molecules

The relative weight of molecules considers the weight of an atom of each element as compared to the weight of an atom of another element. Atomic weight listings have many uses, but one of the most valuable is in determining the relative weights of molecules of compounds. It is easy to add the relative weights of all the different kinds of atoms known to be present in a molecule or a compound. But how can the relative weight of a molecule of a compound be determined when we do not know what elements are in the compound? Discovering methods of answering this question reveals interesting and challenging chemistry projects.

Such projects require associating one or more of the properties of the compound with some kind of chemical behavior that is known to depend on the number and weight of the molecules causing the behavior. Each of the following suggestions illustrates and provides an example of this general kind of chemistry study.

a) If the compound being studied exists as a gas at temperatures and pressures reasonably close to usual room conditions, this property can be used to estimate the relative weight of the compound's molecules. It is known that a quantity of gas equal to its molecular weight in grams will fill a space or volume of approximately 22,400 milliliters at

0 degrees centigrade and at average atmospheric pressure. The measure of average atmospheric pressure is 760 millimeters of mercury. From this, the volume and weight of a quantity of gas can be easily determined. All that is needed to determine the weight of 22,400 milliliters of the gas is a simple mathematical proportion.

For example, suppose a quantity of dry ice (frozen carbon dioxide) weighing 0.44 grams is changed to gas and fills a plastic bag to a volume of 224 milliliters when the temperature is 0 degrees centigrade, and the pressure is 760 millimeters of mercury. Because 224 milliliters is 1/100 of 22,400 milliliters, using mathematical proportion it is evident that 44 grams of the dry ice would have filled a 22,400 milliliter plastic bag. Thus, the relative molecular weight of the gas is 44. Probably, you have already realized that dry ice is solid carbon dioxide and filled the plastic bag with carbon dioxide gas. The chemical symbol for carbon dioxide gas (CO_2) could have been used to derive its molecular weight of 44.

The important thing to learn from the dry ice example is the plan for determining the relative molecular weight of a gas. Notice that the relationship between the volume and the molecular weight in grams of a gas is unchanged only when the gas has a temperature of 0 degrees centigrade and the atmospheric pressure is 760 millimeters of mercury. If the gas you are examining is warmer or cooler than 0 degrees centigrade, the relationship will not be the same as it was, and must be changed. Similarly, if the gas is tested during stormy weather, or if you are on a mountain much higher than sea level, you must change the relationship figures because of the difference in atmospheric pressure.

Suppose, for example, that the carbon dioxide used in the previous experiment had warmed to 27 degrees centigrade before its volume could be determined. Warmer gases require a great volume of space. Therefore, all of the original amount of dry ice would not be needed to produce 22,400 milliliters volume of gas. The fact is that the quantity of dry ice weighing 0.44 grams would have produced more than the 224 milliliters it did produce. But how much more? To answer this question, another method of measuring temperature must be used. This method is called the Kelvin scale. In the Kelvin scale, 0 degrees is the temperature at which gas has 0 volume. This temperature is 273 degrees below freezing on the centigrade scale. Therefore, to convert centigrade temperatures to degrees Kelvin, add 273 to the centigrade value.

From this it can be realized that the gas which had a temperature of 27 degrees centigrade was 300 degrees above the temperature at which it would have 0 volume. To change its warmed volume to what it would have been at 0 degrees centigrade requires multiplying the volume by 273 and dividing it by 300. Using this method of figuring when the 0.44 grams of carbon dioxide were warmed to 27 degrees centigrade, it would have increased its volume to 246 milliliters.

Changes for differences in atmospheric pressure are less complicated. This is because of the relationship between the pressure on a gas and the volume it occupies. Continuing the example, had the 0.44 grams of dry ice changed to a gas on a day when the atmospheric pressure was 770 millimeters of mercury, we should divide the volume of gas (224 milliliters) by 770 and multiply it by 760, and only 221 milliliters of gas would have resulted. To change this volume of gas to the volume it would occupy at the lower pressure of 760 millimeters of mercury, divide the volume by 760 and multiply by 770.

When weighing a plastic bag that has been filled with gas, don't forget that the gas will weigh less in air by the weight of the volume of air it displaces.

b) It is known by most people that dissolved substances change the freezing or boiling temperatures of the liquid in which they are dissolved. This fact can be used to estimate the relative weights of the molecules of the substance that has been dissolved.

It is known that a quantity of a compound equal to the relative weight of a molecule of the compound in grams, when dissolved in 1,000 grams of water, will lower the freezing temperature of the water 1.86 degrees centigrade or increase the boiling temperature by 0.52 degrees centigrade. Can you understand how these facts can be used to estimate the relative weights of molecules of compounds?

It is also known that the effect of dissolved substances on freezing and boiling temperatures depends very much on the number of particles added to the water. If what appears to be a molecule of a compound, when it is dissolved, breaks or ionizes into two or three fragments, for example, the effect on freezing or boiling temperatures will be increased proportionately. Also, if the molecules or molecule fragments of the dissolved substance react chemically with the water molecules, this procedure may result in wrong estimates of molecular weight. Some molecule fragments, for example, cause several water molecules to attach to them and thus change the proportion between dissolved particles and unattached water molecules.

6

BUILDING ATOMS, IONS, AND MOLECULES INTO CRYSTALS

The brilliant blues of crystals formed by the compounds of copper, the delicate pinks of cobalt compounds, or the bright yellow and orange crystals containing chromium are among the most beautiful of nature's colors. The long thin crystals of magnesium sulfate, the square crystals of sodium chloride or eight-sided crystals of alum, or the vastly varied and delicate forms of snowflakes are impressive examples of mathematical design and shape.

But chemists are not content merely to marvel at the pretty colors and shapes of crystals. They want to understand how these colors and shapes are related to the separate atoms, ions, or molecules which form the crystals. Also, they believe that many of the properties of crystal substances depend on how the separate particles are arranged in complex crystal structures. It is probable, for example, that the difference between common coal and expensive diamonds is caused by the differences in the arrangement of carbon atoms. One arrangement produces coal and another produces diamonds.

One major assumption is involved in the effort to describe the properties and characteristics of crystals. We assume that the observable and measurable properties of large crystals are related to the properties and characteristics of the separate atoms, ions, or molecules that are joined together to form the crystals. Because of this, the plan for the study of crystals allows us two different methods of studying a problem. One method is to organize all we can about the atoms, ions, or molecules that are present in the crystal, and then try to decide how their individual properties would produce the properties of the crystal. The other method encourages us to begin by learning as much about the crystal as we can, and then imagining models of the kind of atoms, ions, or molecules that would be needed to give the crystal the properties and characteristics we know it has. In laboratory work, however, the best way is likely to combine both methods.

Often, important information can be obtained by attempting to grow crystals. Some very interesting and instructive projects begin with growing crystals from solutions of one salt or another. There is something exciting about watching crystals grow. A person can almost "see" the individual particles separate from the solution and find their proper place in the enlarging crystal. In almost all cases, the large, perfect crystal we hoped to produce does not materialize. But disappointment quickly disappears as we become curious about what happened, which can help in developing new and different experiments or investigations.

Another method for studying crystals is to build models of how we think the atoms, ions, or molecules are arranged. Various plastics or other materials become the separate particles in the crystals, and small bits of sticks or wire are used to indicate the manner in which the particles are attached to each other. Complicated crystal structures become much less complex when they are converted into models that allow us to "see" how the arrangement of separate particles corresponds to or differs from the properties of the total crystal.

Although each project involving the growth of crystals requires cleverness and intelligence, there are three general steps. First, all impurities must be removed from the solution in which the crystals are to form. Second, the proper "seeds" must be present on which the crystals will grow. Third, special efforts must be made to encourage the growth of large, perfect crystals rather than small, irregular crystals.

Crystal Hairs

The very great strength and other strange properties of metallic "hairs" and their complicated form makes these crystals especially interesting. Copper and iron hairs and also hairs of many salts can be grown with the following procedures.

WARNING: *This experiment can be very dangerous. Hydrogen and air form violently explosive mixtures. The salts should be heated electrically, if possible. Safety glasses and protective clothing are required.*

To grow hairs of copper or iron, hydrogen gas must pass through a furnace containing a special kind of compound of the metal. A chemist might use a mixture of half copper iodide and half copper chloride. This is placed in a very small dish that can be heated. The dish is placed in a large glass tube approximately 2 inches across. The ends of the tube have corks with holes in them for the hydrogen to enter and leave. The hydrogen should be blown across the small dish at a rate of 3 centimeters each second, and the temperature should be between 600 and 800 degrees centigrade. The hair crystals will grow on the sides of the dish (see Figure 8).

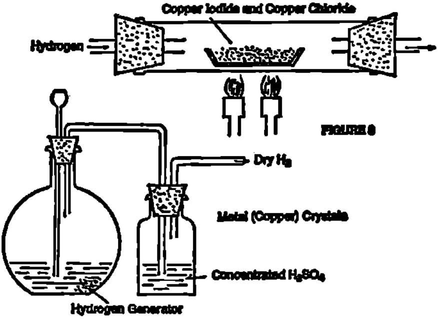


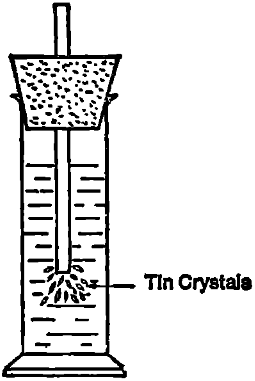
FIGURE 8

To grow hairs of salts, such as sodium chloride or similar alkali metal compounds, a solution of salt is evaporated as follows: Prepare a saturated solution of sodium chloride by putting salt into pure water at 80 degrees centigrade until no more salt will dissolve. Allow the solution to cool and pour off the clear saturated solution. Place a quantity of this solution in a jar with a large opening at the top. Cover the jar with a thin sheet of plastic, or cellophane, and fasten a rubber band tightly around the plastic and the jar. Turn the jar over, and fasten it so that the cover does not touch anything. Large quantities of hair crystals 3 to 5 millimeters long will form. If the crystals do not form, use other kinds of covers until you are satisfied with the results.

Tin Crystals

Crystals of tin can be grown at the place where tin chloride touches hydrochloric tin. The tin chloride solution is prepared by heating to almost boiling 50 grams of tin in 50 milliliters of hydrochloric acid. The flask in which these compounds are heated should be covered during heating to prevent drops of the mixtures from splashing out. After it has ceased reacting, filter the solution through cotton.

FIGURE 8



Put enough 1 N hydrochloric acid in a flask for a depth of approximately 10 centimeters. Place a quantity of the tin chloride solution under the acid in such a manner that the two do not mix. Using a rubber cork with a hole in it, place a rod of tin in the flask. Allow the tin rod to go through the hydrochloric acid and into the tin chloride solution. Hair crystals of tin will soon appear.

If no tin rod is available, one can be made by melting tin and pouring the melted tin into a glass tube of the proper size. Or the melted metal can be sucked into the glass tube. For best results, heat the glass tube before putting the melted metal into it.

Light and Dark Colors in Crystals

If two compounds which form different-colored crystals can be forced to make crystals at the same time from a solution containing both of the compounds, by changing the proportions of the compounds, darker or lighter colored crystals may be produced. Zinc and nickel ammonium sulfate salts can be used for this experiment.

Another pair of salts possessing the necessary properties to allow them to be used in experiments in darker and lighter colors in crystals are chromium potassium sulfate and aluminum potassium sulfate. The solubility of these two substances differs. Twenty-five grams of chromium potassium sulfate can be dissolved in 100 grams of water, while the same amount of water will dissolve only 14 grams of aluminum potassium sulfate. Prepare four different solutions. For example, for a 1:1 solution, use 24 grams of the first compound and approximately 13 grams of the second compound in 100 grams of water. For a 1:2 solution, use 13 grams of the first and approximately 13 grams of the second. Similarly, 1:4 and 1:8 solutions can be prepared.

Place the solutions in a cool room where they will not be disturbed. In one test of this experiment, some solutions were put in a very cold place and hair crystals 3 centimeters long appeared in 2 days. During the same period of time, other solutions in a warm room grew only very small crystals.

If your first attempt to grow crystals is not successful and must be repeated, remember that careful filtering of solutions often improves results.

7

MANAGING CHEMICAL REACTIONS

Chemists do not merely bring their molecules of raw materials or reacting substances together and hope that the necessary rearranging of their atoms will occur. The management of chemical reactions, the control of all things that are likely to influence, start, or change the rate of chemical reactions, is a very important part of chemistry.

The management of chemical reactions is one of the most important parts of industrial chemistry. Obviously, the success of a chemical industry depends on how well raw materials are converted into products that can be sold. Each molecule of medicine, for example, that should be extracted from its source material, but is destroyed or lost during the manufacturing process, reduces the profits of the company.

To become familiar with the factors that influence chemical reactions is of double value to a chemist. The more that is known about the factors which influence a particular chemical reaction, the better we can understand exactly what happens in the chemical reaction. For these reasons, many chemists work for many years learning to describe accurately how various factors influence chemical reactions.

Perhaps we can best appreciate the plan for managing chemical reactions if we consider what a chemical reaction involves. First, the molecules of the raw material must be broken apart. Second, the fragments of the molecules or their individual atoms must not recombine to make the original substance. Third, the molecule fragments or separate atoms must be encouraged to form only the kind of molecules that become the desired product. If these three actions seem complex and difficult, perhaps this is why the management of chemical reactions requires the best-trained chemists of the chemical profession.

The plan for "reaction management" chemistry requires us to learn as much as possible about the kinds and strengths of the attachments that hold the molecules of the raw materials together. Another part of the plan requires us to estimate how much force will be needed to cause the molecules to break apart. Often it is possible to change the conditions of the reaction so that the molecules can be broken apart without too much force being used. Another part of the plan is that we search for a kind of mystery compound called a **catalyst.**

We must also learn as much as we can about the conditions which help the molecular fragments to recombine into the desired compounds rather than return to the original raw materials. To do this, we must discover methods of strengthening the bonds of the atoms of the desired product and also try to weaken the bonds between similar atoms while they are still in the form of raw materials.

Often it is wise to imagine or create a series of actions to encourage the reaction we desire. If there are several different kinds of atoms in the molecules of the raw materials, for example, we cannot expect all of the molecular fragments or single atoms to join together immediately. It is much more probable that the raw-material molecules will break apart and that the molecules of the desired compound will rearrange slowly. This requires us to imagine other compounds that may be formed before the compound we desire is formed. These compounds may exist for a few seconds only, but the success of the experiment will depend on their existing for those few seconds.

There are some things we know that help in the work of chemical reactions. To increase the temperature of a reaction forces the molecules in the reaction to move with greater force. Because of this, the molecules of the raw material will break into smaller fragments. But remember that the desired compound will also be at the increased temperature and may also be changed from what we want because the atoms are moving with greater force.

Similarly, to increase the number of molecules of the raw materials is to increase the number of contacts between molecules that will react with each other. If the number of molecules that contact other molecules during any single instant is the factor that limits the success of our reaction, to increase the number of molecule contacts will certainly increase the speed of the reaction. It is also possible, how ever, that the bonds between atoms are too strong to be broken, and nothing can be gained by merely increasing the number of contacts between molecules.

Thus, because "reaction management" chemistry is difficult and has many factors influencing it, beginning chemists who like a challenge will find much to interest them in this work.

Describing a Chemical Reaction

Although bright changing colors, bubbling gases, explosive flames, or solids in the bottom of a test tube provide evidence that something is happening during a chemical reaction, such things do not completely inform us of what is actually occurring. Detailed descriptions of chemical events require that the chemist imagine he is entering among the atoms that are being rearranged, that he notice what changes are occurring, count the number of atoms and molecules involved, and try to understand why the new molecules are preferred to those that existed before the reaction began.

To hope to describe a chemical reaction requires every bit of intelligence and imagination possible. The chemist cannot describe a chemical reaction only by weighing and measuring compounds and elements. He uses ideas and models of what he imagines is happening in the invisible atoms and molecules.

The plan for this experiment can be used in the description of many chemical reactions. The procedure is listed in a series of actions. However, the objective of the experiment should not be forgotten and, after some experience, beginning chemists will be able to start with chemicals about which they know very little, notice the reactions between these chemicals, and then intelligently describe the atom-molecule rearranging.

1. Obtain 10 grams each of potassium iodide and lead nitrate. Dissolve a few crystals of each compound in a milliliter or two of pure water. Obviously, a reaction occurs. It is this reaction that is to be described.

2. Because the yellow solids in the bottom of the test tube are the most obvious result of the reaction, try to describe what kinds of particles produce the yellow color. Assume that the original compounds contained potassium, lead, iodide, and nitrate ions, but almost nothing else is known about the reaction. The possible materials that could be produced would include: potassium, iodine, lead, potassium nitrate, lead iodide, and many other combinations of these particles.

3. Assume that the following compounds are the most likely to have occurred: potassium nitrate, lead oxide, lead iodide, or several other similar compounds of the atoms of lead, potassium, oxygen, and iodine. The first problem is to arrange these possibilities in the order in which they are to be tested. How to proceed depends on the chemicals available for testing. If there is potassium nitrate available, very little time or effort are needed to dissolve a small quantity in water to discover whether yellow solids are formed. Thus, although potassium nitrate was not the most likely compound

to be formed, because it could be tested so easily this test could be accomplished first.

4. Some kind of lead iodide compound is likely to be the most probable compound formed. The experiment continues to determine the proportion of lead and iodine particles in the molecules of this compound. Consider the relative atomic and molecular weights to prepare solutions of potassium iodide and lead nitrate so that the same amounts of the two solutions contain equal numbers of iodide and lead particles. To do this, weigh quantities of the two compounds according to their molecular weights. For example, the relative molecular weights are 166 for potassium iodide and 331 for lead nitrate. Therefore, 1.66 grams of potassium iodide and 3.31 grams of lead nitrate each dissolved in 100 milliliters of water will produce solutions containing equal numbers of iodide and lead particles.

5. Put 6 milliliters of the potassium iodide solution in each of twelve test tubes. Add 1 milliliter of the lead nitrate solution to the first test tube, 2 milliliters to the second, 3 milliliters to the third, and continue increasing the amount of lead nitrate solution added to each of the twelve test tubes. Shake each tube to mix the solutions and allow them to be undisturbed for several hours.

6. Study the twelve test tubes and decide what is the proportion of iodide and lead particles that produces the most of the yellow solid in the bottom of the test tubes.

7. Use the plan of this experiment to examine and describe reactions between such solutions as

silver nitrate and potassium chromate; barium chloride and sodium sulfate; lead nitrate and potassium chromate; and zinc chloride and sodium phosphate.

The Chemistry of Colors

One part of describing a chemical reaction involves the ability to relate something that happens when a reaction occurs to one or two kinds of particles which are principally responsible for what can be observed in the reaction. The colors which result from some reactions provide a good example. The suggestions listed here enable you to observe several colorful reactions, but no details are listed for planning experiments in which a particular color change can be associated with particular kinds of atoms, ions, or molecules. By rereading the types of experiments described in Chapter 1 of this book, plans for color-chemistry experiments become readily apparent.

1. Prepare 50-milliliter portions of each of the following solutions in 100-milliliter beakers: sodium salicylate, strontium chloride, potassium ferrocyanide, tannic acid, and sodium bisulfite. Prepare enough ferric ammonium sulfate solution to allow you to pour 25 milliliters of this solution into each of the five beakers.

2. Prepare the following mixtures of chemicals by placing approximately 1 gram of each mixture in a 50-milliliter beaker: ferric ammonium sulfate and tannic acid; strontium chloride and sodium carbonate; sodium salicylate and ferric ammonium

sulfate; cobalt chloride and sodium carbonate; calcium oxide and a few drops of phenolphthalein solution; ferric ammonium sulfate and sodium carbonate; sodium ferrocyanide and ferric ammonium sulfate; cobalt chloride and sodium ferrocyanide; sodium ferrocyanide and ferric ammonium sulfate. Add approximately 50 milliliters of water to each of the nine beakers.

3. Mix together with a mortar and pestle equal portions of manganese dioxide and sodium hydroxide. Heat the mixture in a crucible strongly for 30 minutes. Allow the mixture to cool, and to the black solids in the dish add some water. Then add a few drops of sulfuric acid. Allow the solution to be undisturbed for a couple of days.

4. Boil red cabbage leaves in water for 30 minutes. Filter the solution through cotton cloth. If the solution is not a very dark blue color, evaporate part of the water. To one portion of this solution add a drop or two of sulfuric acid. To another portion add a drop or two of ammonia solution. Interesting things can be seen if the acid or ammonia solution is allowed to flow down the side of the container without stirring or mixing the solutions. Better results can be obtained if the water solution from boiling the cabbage leaves is mixed with one-eighth of its volume of alcohol.

8

DESCRIBING CHEMICAL ENERGY

A rocket rises from its launching pad surrounded by clouds of smoke from its engines. The motor of an automobile roars as it moves the car up a steep hill. And in green plants throughout the world the sun's rays are being absorbed and the sunlight stored in foods rich in energy, energy that can be released by combining with oxygen to help life continue in all kinds of plants and animals. Actually, energy is so closely associated with the rearranging of atoms from old to new molecules that attempts to describe the "energy" of chemical reactions is one of the most important of all the different kinds of chemistry.

But energy chemistry is not one of the simplest kinds of chemistry. Energy is not easy to describe. Energy cannot be directly weighed, watched, or measured. It must be described by describing what it accomplishes. To measure the amount of energy associated with a chemical reaction, the plan is to measure something that the energy does while it is being converted from one form to another. Discovering how much energy there is in a drop of gasoline, for example, is best done by burning the gasoline and "catching" the energy that is released as heat in a carefully measured amount of water. How much the temperature of the water is increased can then be used to figure the amount of heat that must have been in the drop of gasoline. However, it must be remembered that there is also an amount of energy that does not go into the heating of water. This is the energy that becomes water vapor, carbon dioxide, or other gases formed when the gasoline burns.

The energy of chemical reactions can often be revealed in the relationship between the rearranging of atoms and electrical events and circumstances. Differences in the electricity in molecules and atoms cause many chemical reactions. Similarly, chemical reactions are likely to produce differences in the electricity in atoms and molecules. There are electrical instruments that measure these differences in electricity. Thus, another method of studying chemical energy is to use the relationship between the rearranging of atoms and the accompanying energy changes in the form of unbalanced electrical charges.

Everyone who has used a camera knows that the chemical reactions of photographic film are particularly sensitive to energy in the form of light. More painful evidence of the role of light in chemical reactions is the tender and red skin resulting from being exposed for too long a time to the summer sun. Because the tiny bits of energy of which light is composed come from motion in the atoms or molecules, the colors and brightness of light accompanying the rearrangements of atoms and molecules are extremely helpful in describing the energy in chemical reactions. The measuring of colors that are either released or received when chemical reactions occur has become the most used form of planning in modern energy chemistry.

When we think about this for a moment, we realize how our modern manner of living depends on having available convenient and almost unlimited energy resources. Engines or machines powered by the wind, rivers, or horses can never provide all the energy the modern world requires. Therefore, scientists are continuing to learn how to use and control the enormous quantities of energy that are released by the splitting or joining of atoms.

Heat of Solution

The receiving or release of energy, usually in the form of heat, has a great effect on chemical reactions. This is not at all strange. Combinations of atoms are no more likely to be rearranged without energy being involved than is the mixing of cards used in card games. If a small amount of energy is used to push the cards off a table, the total energy used in scattering the mixed cards comes from more sources than the push that sent them to the floor. Often, only a small amount of energy starts a great amount of energy to be used in the rearranging of atoms among molecules.

Changes in the arrangement or motion of any group of atoms, ions, or molecules are certain to be accompanied by either the gain or the loss of energy. Thus, the gaining or losing of energy begins when substances are being dissolved. If the newly dissolved particles react with each other or with the molecules of the solution, more energy changes occur.

The substances used to clean drains that have become blocked by material that will not permit water to flow through the drain are an excellent example. The chemical energy of these substances is very strong. Actually, people have been burned because they did not know of the great amount of heat that can be produced when these substances become part of a solution and react with the material that is blocking the drain. Investigating this reaction is an example of a project for energy chemistry, which also provides knowledge that may help to prevent painful accidents when using energy-creating substances.

1. Place 100 milliliters of water in a small beaker and place the small beaker in a larger beaker. Place paper between the two beakers for insulation. Use a thermometer to measure the temperature of the water.

2. Read the printing on the side of a can of drain-cleaning compound. With *caution* remove 1 gram of the drain-cleaning material. With continued *caution* add this small amount of the compound to the 100 milliliters of water in the small beaker, stirring the mixture with a glass rod while adding the water. Use the thermometer to measure how much the temperature increases. Save this solution for use in step 5.

3. Knowing that 1 **calorie** of heat raises the

temperature of 1 milliliter of water approximately 1 degree Kelvin, figure how many calories of heat were taken by the water when 1 gram of drain-cleaning compound was dissolved.

4. The printing on the side of the can will inform you what the principal chemical in the compound is. If it is sodium hydroxide, for example, weigh a 1-gram amount of this compound and repeat steps 2 and 3. Compare the energy of this compound with that of the drain-cleaning substance.

5. Place 80 milliliters of water and 20 milliliters of vinegar in a 250-milliliter beaker. **Insulate** this beaker as in step 1. Record the temperature of the vinegar solution. Warm or cool it so that it is the same temperature as the solution that was saved after step 2.

6. Combine the two solutions with *caution.* Stir and record the temperature increase. Figure the change in amount of heat that was taken by this 200 milliliters of liquid, assuming this solution has the same heat capacity as water.

7. Prepare another 100 milliliters of the 80-to-20 vinegar solution. Weigh another gram of the drain-cleaning compound. Record the temperature of the vinegar solution and with *caution* add the dry compound to the vinegar solution. Stir and figure the amount of heat the solution takes under these conditions.

8. Notice that step 7 is almost the same as steps 2 and 6 combined. Do you have any questions concerning the results from steps 3, 6, and 7? Remember that in chemistry, nothing is lost; neither molecules nor energy.

From Chemical to Electrical Energy

Ordinary batteries convert chemical energy to electrical energy. Their life is limited by the amount of reacting chemicals they contain. A device that can convert the chemicals flowing through it into electrical energy is called a "fuel cell." Theoretically, it should produce electricity as long as the required chemical "fuel" goes through it. An example of one type of fuel cell is shown in Figure 10. This is how a kind of fuel cell can be made:

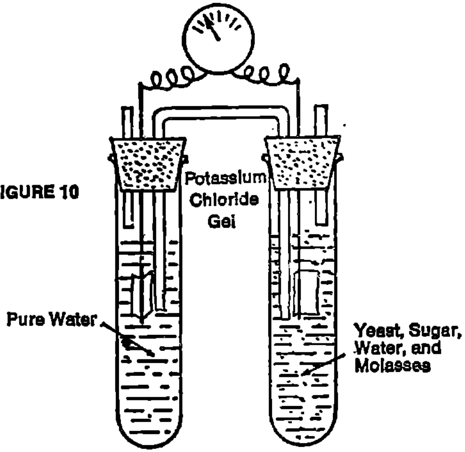
1. Obtain two large test tubes. Put a rubber cork, with two holes in it, in each test tube. Get approximately 250 millimeters of glass tube. Bend the glass tube so that it can be used as a connection between the two test tubes. The ends of the glass tube should extend approximately to the middle of the test tubes. Place the bent glass tube in one hole of each of the rubber corks.

2. Place glass tubes, longer than the rubber corks, in the other holes of the rubber corks to be certain that gas can be released.

3. Force platinum wires through the rubber corks. The top end of the wire should be an inch above the rubber cork. The lower end of the wire should be attached to small pieces of platinum 1 centimeter square in the test tubes.

4. Paint the square pieces of platinum on the ends of the wires with platinum black. This can be done by dipping the platinum squares into a solution of a platinum compound and then adding powdered zinc.

FIGURE 10



5. Prepare enough saturated solution of potassium chloride to fill the glass tube that connects the two test tubes. While stirring this solution, add agar to produce, when cold, a thick, firm gelatin. While this solution is warm, fill the glass tube connecting the two test tubes with the solution. Dip pieces of filter paper into the potassium chloride solution and push the paper into the ends of the glass tube. There must be no air bubbles in the glass tube, in the paper in the ends of the tube, or in the gelatin.

6. Fill one test tube almost to the top with pure water. In the other test tube place an equal amount of a solution containing **yeast**, sugar, water, and **molasses.**

7. Combine all the parts of this system as shown in Figure 10. Using an instrument that will measure

electricity, connect wires to measure any electricity that may be created.

There are many theories imagined by chemists as to why this electricity is created. Most of these theories involve the reaction of yeast and platinum black.

One theory is that when the yeast is used, sugar is converted by the enzymes of the solution through several different compounds until it becomes phosphoglyceric acid. After several other reactions and changes it becomes ethanol. The ethanol comes from the yeast and helps the chemical device to produce electricity.

Another theory to use in experiments with this device is that the yeast and sugar in one of the test tubes combine with oxygen. Because of this, ions move from one test tube to the other. Because the function of the bent tube filled with gelatin is to allow the ions to move from one tube to the other, the same kind of system can be constructed using a thin piece of plastic between the two different fluids. This plastic sheet would allow the ions to move through it, just as they move through the glass tube filled with gelatin. There would be a measurable relationship between the amount of sugar used in this experiment and the amount of electricity created.

9

SPECIALIZING IN A PRODUCT

Specializing is an important part of modern existence. Physicians and surgeons, for example, do not attempt to become skilled at curing all diseases, or correcting disorders in all parts of the body. Painters specialize in using special kinds of paints, and farmers concentrate their efforts on growing only a few kinds of crops or cattle. Similarly, when chemists have learned the facts and skills that are the fundamentals of chemistry, many of them begin to use more of their time and energy in intensive study of a single type of compound.

Specializing allows a chemist to acquire more detailed knowledge of a few kinds of atoms and how these atoms are best rearranged to form molecules with desired properties.

Whatever one's specialty may be— drugs or dyes, pigments or perfumes, alloys or alkalis—projects in this kind of chemistry can begin with a study of what it is that gives a substance its special values. Methods must be discovered to measure the strength of these special properties in a substance, and it must be possible to compare the effectiveness or value of the same substance manufactured by different companies.

Discovering the source of the useful properties of a substance is another type of project for the specialist. This will involve the kinds of atoms in the molecules of the substance, their amount, their arrangement, or all of these factors. Chemicals that contain arsenic and kill insects, for example, probably kill the insects because of the arsenic. But other such chemicals consist of molecules containing atoms of carbon, hydrogen, oxygen, and sulfur. These elements are present in the bodies of healthy plants and animals. Thus, a chemical that contains these elements and is used for killing insects must have its bug-killing properties because of the special number and arrangement of atoms of these elements.

Another phase of specializing is to discover facts about the raw materials needed to manufacture your product. Important information includes where these materials can be obtained, how easy they are to obtain, and their cost.

Much can be learned about a product by studying how it is made, and the best method of doing this is by preparing small amounts of the product. Many products can be made in small laboratories, and projects of this type not only yield some of the product for the chemist's use, but also allow him to understand how the raw materials change into the new product. This kind of experiment also teaches the chemist to be careful of the quality of his product.

One kind of chemistry is devoted entirely to controlling the quality of products. When a product made by a company is claimed to be better than a similar product made by another company, it is the quality-control chemist who must be certain that it is superior in quality. Medicine that is supposed to contain a certain amount of a compound must contain exactly the proper quantity, no more and no less. When a new dye for cloth is advertised as not fading in sunlight, control chemists must experiment with every possible combination of circumstances that might allow cloth colored with this dye to fade.

If your specialty is a compound, control of its quality is easier because each molecule of a compound is composed of exactly similar atoms. The problem in this case is in being certain that the product continues to be pure. Manufacturers of canned baby foods, for example, know that when a mother opens a second can of food, she expects the contents to look and taste exactly the same as the last bit of food she took from the previous can. Establishing methods of measuring how well a product equals these standards challenges the best quality-control chemists.

Polymers and Polymerization

On a kitchen shelf, a bright-yellow food package is covered with a thin clear material. But what you see is a marvel of modern science. Have you ever touched a modern plastic and thought about the chemistry that created it? Polymerization is the source of this chemical wonder—the connecting of simple molecules to form complex molecules. Before the twentieth century, men depended on the materials of nature for his cloth and his building materials. A few years ago, people did not know of **synthetics.** Today we are familiar with many of the synthetics, such as nylon, styrofoam, polyethylene, polystyrene, latex and polyvinyl. These substances are known and valued for their remarkable properties.

Today's synthetic materials created by polymerization can be produced in nearly every color, or can be made as clear as the finest glass. They can be so strong that gunshots will not break them, as soft as feathers or as hard as steel, or they can stretch like rubber. It is the special arrangement of atoms in molecules and the connecting of molecule to molecule that gives a plastic its special properties. For example, ethylene gas polymerizes to make the plastic polyethylene. When one of the hydrogens of ethylene is replaced by another atom or group of atoms, its polymer is called vinyl.

Polyvinyl chloride is a common vinyl plastic. With the aid of a catalyst and heat, vinyl chloride molecules are forced to break the connection between the two carbon atoms and join with other molecules in long threads of molecules. The chain of molecules grows longer and longer and the clear gas of the original molecules gradually changes into a firm plastic mass.

Not all polymers are man-made. They occur in nature and are the basis for important products used by people. Natural polymers include cellulose, and such plant and animal products as cotton and wool. Rubber is another natural polymer. The first natural polymers improved by man were cellulose nitrate and casein formaldehyde. A great number of synthetic polymers followed.

In 1846, a chemist in Switzerland accidentally mixed nitric acid, sulfuric acid, and cotton, and produced the explosive named nitrocellulose or guncotton. It required 50 years of study for chemists to learn how to produce and control this material in large quantities. Similarly, in 1868, a printer discovered celluloid while working with collodion, a substance used for making films such as those used for photographs. It is made by dissolving collodion cotton in a mixture of alcohol and ether. He softened the hard film into a soft plastic by adding a small amount of camphor to the warm solution.

Any single plastic is likely to be the result of one of two distinctly different kinds of polymerization processes. In one type of process, the molecules are simply joined together to produce the new polymer. In the other type of polymerization, a fragment breaks off the molecules, and the large parts of molecules form the polymer molecules. Water or ammonia molecules are examples of the kind of fragments produced by this type of polymerization. Obviously, different plans must be used to accomplish each type of polymerization. Beginning chemists should become knowledgeable about both types of polymerization because both can be produced in ordinary school chemistry laboratories.

The Freezing of Solutions

It is known that dissolving a substance in a **solvent** lowers the freezing temperature of the solvent. Automobile engines which are cooled by water and are used in areas where the temperature is below freezing usually have alcohol or some other liquid that will not freeze added to the water to protect against freezing.

In theory, any substance that can be dissolved will serve to protect water against freezing. Actually, only those substances that will not affect the metal and will not stop the water from going through the pipes of the engine can be used. One interesting experiment is to compare the effects of several different solutions on aluminum, iron, rubber, plastic, and other materials likely to be used in the parts of the engine through which the water must pass.

Learning about the property that is involved when a compound is added to lower the freezing temperature of a solvent can indicate other valuable chemistry projects. For example, is the amount of freezing-point depressions obtained proportional to numbers derived by dividing the weight of the water by the weight of the material added? Or is it more closely described by numbers obtained by dividing the volume of water by the volume of material added? Another possible relationship involves the comparing of the number of water molecules and the number of particles of the added solution. When experimenting with this last theory, remember that the molecules of some substances become ions in solution, and produce more than one particle for each molecule of a substance that was not ionized.

Ion-Exchange Chemistry

Many chemical reactions involve rearranging of fragments rather than atoms or molecules. This rearranging involves movement, and the movement requires some kind of power to make the atoms and molecules move. Obviously, atoms and molecules have neither legs, wings, wheels, nor any other of the usual things required for movement. But some of them contain unequal amounts of positive and negative electricity, and therefore have a definite electrical charge. These charged atoms or molecules are called ions. Ions can have either positive or negative electric charge. Like-charged ions resist each other. Ions of unlike charge are attracted to each other.

The forces that exist between different kinds of electricity in atoms and molecules are most useful in explaining the movement of particles during chemical reactions. Although heat was described as motion, causing contact between particles, electric forces must be used to explain why some particles remain together rather than separate after these contacts. We know that heat speeds the motion of all kinds of particles, but atoms and molecules have definite preferences for going toward rather than away from special kinds of electricity.

Any method that helps chemists to manage or control ions is of value to the chemists. Ion-exchange materials provide such help. These substances were first discovered in natural compounds, but they can now be produced in laboratories. Their function is to exchange one kind of ion, which is already present in their molecules, with other kinds of ions, which come near or contact the molecules in the ion-exchange material. The types of ions exchanged depends on the types of materials used in the chemical reaction.

If a fragment of an ion-exchange molecule breaks away in such a manner that the fragment has a special kind of electricity in it, only another ion with exactly the same kind of electricity can enter the ion-exchange molecule in its place.

It may be that a complex particle of material may contain two different kinds of electricity. In such a case, if another ion comes near, it may contact either one or the other of the kinds of electricity. If the electricity is the same, an ion exchange may occur; if the electricity is different, it may not. This is an important fact to remember when attempting to describe some types of ion-exchange action.

The ion-exchange that occurs in some kinds of soil is important in the study of soil chemistry. For this reason, soils are used in the following experiment, which has been designed to acquaint beginning chemists with ion-exchange chemistry.

1. Obtain quantities of as many different kinds of ion-exchange materials as you can.

2. Collect approximately 2.2 pounds each of several different kinds of soil.

3. Dry the soil. Put the different kinds of soil

through screens so that all of the particles will be of the same size.

4. Study available literature describing the properties of the ion-exchange materials. If you desire, however, you may choose to determine these properties by your own experiments.

5. Bake the different kinds of soil in a hot oven for 30 minutes. Allow them to cool, and store them in corked glass bottles.

6. Obtain several glass tubes approximately 250 millimeters long. The hole in the tubes should be approximately 5 millimeters across. Insert a small amount of cotton in one end of each tube and close the tube with a one-hole rubber cork. In the hole in the cork place a glass tube. On the glass tube place a rubber tube with a clasp to open or close the rubber tube.

7. Fasten the glass tubes with the open end up. Fill each tube two-thirds full with a different kind of soil mixed with ion-exchange material, and mark the tubes. Add enough pure water to moisten the solid materials.

8. Prepare a liter of 0.01 M barium chloride solution. Determine whether it is acid or alkali. Observe how small amounts of this solution react with equal amounts of solutions of 0.01 M silver nitrate and sulfuric acid.

9. Place 10 milliliters of the barium chloride solution in each of the ion-exchange and soil tubes. Determine whether the liquid passing through each tube is acid or alkali, and notice how these liquids react with silver nitrate and sulfuric acid.

10. Knowing that metallic ions contain different

electricity than ions that are not metallic, compare the effects on various solutions passing through the tubes.

10

SPECIALIZING IN A PROCESS

The modern tendency toward specializing in science provides opportunities for chemists who choose to become process experts. The procedures or skills used in many kinds of chemistry require rare talents or many years of training. Glassmaking, for example, can require much time and produce many disappointments for some people. A talented glassmaker, however, can design complicated machines to assist him in his work and enjoy, rather than be disappointed by, his work.

A chemist who works in a laboratory operating special instruments can weigh or measure more exactly with his instruments than a chemist who is less familiar with the characteristics of the instruments.

Chromatography experts often suggest the kind of solvent most likely to separate a complex mixture into its different elements and compounds, or provide valuable assistance by alerting other chemists to mistakes that have happened in similar experiments. Beginning chemists who decide to gain all possible knowledge of a chemical process and become experts in working at this process can expect to find good jobs in the chemical profession.

To become an expert in any chemical process requires as much knowledge as possible about the theories and principles that are used in the process. And this knowledge cannot be gained completely from books. The trained and talented process expert, watching his instruments, is actually seeing the effects that accompany the rearrangement of atoms in a chemical reaction. However, many other chemists who would become successful process experts become so interested in their complicated instruments that they forget the chemical problems that their instruments would be able to help them solve.

Process experts, however, are encouraged to know what their instruments can do, and to develop methods of improving their instruments. Because an instrument can seldom deal with individual atoms or the effects accompanying a single rearrangement of atoms, it is wise to establish the probable errors an instrument can be expected to produce. The best process experts are always attempting to improve the design of their instruments.

Chromatography

One of the things chemists are asked to do is to separate or extract a single substance from other substances. Other important functions of chemistry involve proving that a substance contains only one kind of atom or molecule, or that an unknown substance is or is not the same as an already identified element, compound, or mixture. To realize how often chemists are required to use these skills is to understand why chromatography has become one of the most frequently used and most advanced processes of chemistry.

The property of substances used in chromatography is one of the easiest to understand at the elementary level. You can see the property in action when drops of paint or other colored liquids are spilled on paper, cloth, sugar, or other materials which consist of tiny particles or threads. The spilled liquids spread through such materials and if the proper conditions exist, the spreading spot is not all of exactly the same color. As the molecules of the liquid are spread through the material, some seem to move more slowly than others through the tiny particles and threads of the material in which they are spreading. Apparently, each kind of atom or molecule is different in the manner in which it moves through the particles and threads of the material. Can you imagine how this difference can be used in the design of processes to separate single kinds of atoms or molecules from complex mixtures?

The materials needed to separate substances by chromatography consist of a substance to provide the net of particles or threads, a moving stream of particles through this net, and methods to locate and recognize the chemicals in the separate spots or bands in the stain in the material. To say it in other words, the net of tiny particles or threads is the still part of the process, the substance being separated is the moving part, and the stream of particles is the liquid or gas solvent.

Filter paper of various thicknesses is used often for the still part of the process. Powdered substances dissolved in liquids or spread evenly over glass surfaces produce thin layers of nonmoving particles when the liquids evaporate. This is called thin-layer chromatography and it is used by many chemists. To fill glass tubes with the still part to produce columns of particles or threads through which the moving part and the solvent move is another well-known method.

The moving part or solvent can be any liquid or gas that will spread through the still part and neither dissolve nor react with the particles or threads of the still part nor with any of the substances being separated. The action of the solvent must be limited to moving the atoms and molecules of the substance being separated as they spread through the still part. Obviously, there is knowledge and skill involved in matching the properties of the solvent with those of the substance being separated and of the material used in the still part of the process. If the solvent's particles become attached to the different kinds of particles to be separated, for example, they will all remain with the moving part. Similarly, if the solvent does not force the particles of the moving part to move through the still part, the separating of the desired substance will not be accomplished.

When the raw material to be separated consists of many different kinds of atoms or molecules, it may be necessary to use first one and then another solvent to separate all of the substances in the raw material. The experiments in this chapter will show you several methods to use in solving this problem.

To locate and recognize the chemicals in the separate spots or bands in the still part of the process requires a certain skill. Colored chemicals cause the least trouble. Some colorless substances can be made to glow by using special lighting devices. Most often, a reagent must be used on the entire still part of the process. This reagent must react differently with each of the separated substances. If we know the colors of the products produced by the reagent's reaction, and any of these colors appear, then we can assume that the substance that reacts with the reagent to produce the color must have been present in a spot or band on the still part of the process. The reagent to be used obviously depends on the properties of the substances to be separated.

To remove the separated substances from the still part of the process is another problem. The atoms or molecules we want are mixed with the particles or threads of the still part. It is probable that they are not connected chemically to these particles or threads, but are merely mixed with them. The best thing to do is to cut the spots from filter paper, scrape from thin-layer glass the desired spots or bands, or push the columns through the glass tubes and cut out those portions which contain the separated substances. Now the problem is to separate the substances from the paper thin layers, or column material. This is usually done by washing the spots of column material with a solvent, filtering to remove the unwanted substances, and getting the desired substances by evaporating the solvent.

The successful worker learns subtle methods of improving his work, in addition to understanding the principle of chromatography. First efforts are likely to produce spreading colors rather than spots or bands. Sometimes the raw material must be purified before its substances can be separated by chromatography. The following experiments will acquaint you with some of the rules of chromatography, and invite you to learn how to discover errors in your methods.

Separating Food Colorings With Chromatography

1. Use ordinary wrapping paper to practice cutting sheets of paper and making them into tubes. Bend the paper in a circle until the edges touch, and fasten the edges. The tubes of paper should be as large as possible, but they should go easily into the jars you have available. The length of the paper tubes should be 1 inch less than the height of the jar.

2. Using a wrapping-paper pattern both to indicate size and to avoid having the marks of your fingers on the paper, cut several sheets of filter paper (still part) to the proper size.

3. Draw a line with a pencil on the filter papers ½ inch from the side that will be the bottom of the tubes. Two inches apart, draw circles with a pencil. The circles should be ¼ inch across.

4. On other pieces of filter paper, and using a glass tube with a very small hole in it, practice putting a spot of food coloring in each ring. Use just enough food coloring to fill the ring.

5. Using one of the pieces of filter paper you

have cut to make a tube, write in pencil the name of the color you will put into the circles. You may want to mix colors for some of the spots. Avoid leaving finger marks on the paper.

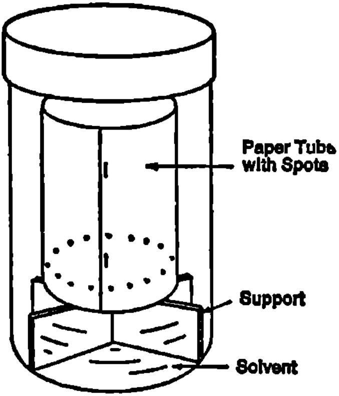
6. Put food coloring in the rings. Allow the spots to dry.

7. Prepare supports for each jar by making an X of pieces of thin plastic. These supports should hold the paper tube ¾ inch above the bottom of the jar.

8. Place the X-shaped support in the jar and add water to ¼-inch depth in the jar. You should attach a strong thread to the X-shaped support to assist in placing it in the jar and removing it.

9. Form the sheet of filter paper with its dry food-coloring spots into a tube, fasten the edges, and place it in the jar. Do not allow the paper to become wet. Put a lid on the jar and allow it to be undisturbed for 12 hours (see Figure 11).

FIGURE 11



10. Remove the paper tube and the plastic support. Place the paper tube back in the jar without the plastic support and put the lid on the jar.

11. Watch to see what happens.

You may want to try one of the following suggestions so that you will better understand what is meant by matching the properties of the solvent with those of the substance being separated:

1. Use other types of filter paper or try other kinds of paper.
2. Make the water used as a solvent more acid or more alkali.
3. Use another solvent.
4. Try other kinds of food coloring.

Column-Chromatography Separation of Carotene Pigments in Tomatoes

1. Obtain a glass tube 30 centimeters long and approximately 1 centimeter across. Be certain the tube is clean and dry.

2. Fill the bottom 1 inch of the tube with cotton. Pour powdered alumina into the tube. Use a folded paper and pour the alumina so that it falls into the center of the tube. Have an assistant tap the tube gently while it is being filled. Fill to 10 centimeters from the top and add a centimeter of washed sand to protect the top of the column.

3. Use a mortar and pestle to crush 50 grams of a tomato. Add 50 milliliters of methanol and mix with the tomato.

4. Add 50 milliliters of methanol and pour this solution into a 300-milliliter flask. Add 100 milli-

liters of petroleum ether and put a cork in the top of the flask. Shake the mixture for 15 minutes.

5. Filter the mixture. To the liquid that has passed through the filter add an equal amount of water. Shake this mixture for 5 minutes. Use a separatory funnel to divide the two layers of material. The petroleum ether layer contains the dissolved pigments. Wash this layer several times, using small amounts of water.

6. Use steam or an electric heater (CAUTION: *the vapors will burn easily*) to evaporate the petroleum ether until only 20 milliliters remain.

7. Place a one-hole cork in the bottom of the glass tube containing aluminum oxide and use glass and rubber tubes to connect a water pump to suck air through the tubes. *Carefully* pour several milliliters of the petroleum ether-pigment solution into the top of the tube. The pump should make the pigment flow through the tube at a rate of approximately 25 millimeters a minute.

8. When the last part of the pigment solution is in the top of the tube, add 15 milliliters of petroleum ether in 5-milliliter portions.

9. After all the pigment solution is in the column, close the rubber tube at the bottom of the column so that the solution remains in the column.

10. Arrange the device as it was for step 8. Begin adding 5-milliliter portions of ligroin to the column. Colored zones should appear in the column. Continue adding ligroin until the lowest-colored zone is near the bottom of the column. Near the top of the column there should be a small red zone of lycoxanthine. Below it there should be a broad red

zone of the main pigment lycopene. Below this there are several small zones, and at the bottom of the column a broad orange-colored carotene zone.

11. Allow the column to become nearly dry. Place a small amount of cotton in the top of the tube to prevent spilling. Prepare to push the column from the tube. Tap the tube against the palm of your hand to loosen the alumina. Lay the tube on a clean surface. Put moist paper in the top of the tube, and with a wooden rod push the column from the tube. Cut away the carotene band and put it in a flask containing 50 milliliters of a 75 percent ligroin-25 percent methanol mixture. Shake and filter. To obtain the pure carotene pigment, evaporate the solution in a vacuum.

11

APPRECIATING NATURE'S CHEMISTRY

Almost all chemistry is nature's chemistry. Men have produced atoms other than those of nature only by building great machines called cyclotrons with which to force fragments of atoms into other atoms. Only by inventing these machines have men succeeded in changing the chemical behavior of nature's original atoms.

Chemists look to nature not only for the raw materials to put into their crucibles and flasks, but also for ideas to help them discover new and valuable inventions. Perhaps in the future some very, very brave chemist may believe that the body does not need to grow old and used in the 70 years that most people can expect to live. This chemist may discover something that will help him find a not yet discovered "aging" enzyme, catalyst, or other and perhaps even more mysterious substance.

A chemist of the future, studying the ability of birds and other animals to travel long distances, may attempt to discover a substance that has not yet been imagined, a substance that will have a kind of energy that we do not yet know. Or it may be that in the odd happenings of nature some future chemist may discover a new theory of how the rearranging of atoms causes a child to have the same characteristics as its parents.

In nature's chemistry are problems to challenge the minds of the world's most courageous chemists; problems that require not only trained hands and minds, but also the ability to believe theories that other people might consider ridiculous.

To suggest plans and methods for any kind of chemistry is difficult, but the difficulties become almost impossible when dealing with nature's chemistry. We know that the study of nature's chemistry requires men and women who are sensitive and interested in the world around them. They must admire the order and beauty of nature and be curious about how things become orderly and beautiful. They must respect the great power and force of windstorms, floods, and lightning flashes, and at the same time believe that ultimately such forces can be controlled.

When nature seems to act in a uniform manner, the inspired chemist attempts to use that uniformity to create laws or principles for science. He must be able to understand, measure, and describe, usually in mathematics, nature's uniformities. Similarly, things in nature that seem not to be uniform, or that seem to disprove theories that chemists have always believed, are especially welcomed by those who study nature's chemistry. The history of chemistry shows how often the unexpected happenings of nature, or the experiments which do not produce the expected results, help reveal new discoveries and inventions.

Because they encourage beginning chemists to study nature, projects in which nature's uniformities or differences are studied can be very useful and interesting. And when a chemist can recreate in his laboratory what he has seen happening in nature, he is aiding the forward progress of science.

ELEMENTS—THEIR SYMBOLS AND ATOMIC WEIGHTS

Element	*Symbol*	*Atomic weight*	*Element*	*Symbol*	*Atomic weight*
Actinium	Ac	227	Copper	Cu	63.54
Aluminum	Al	26.98	Curium	Cm	245
Americium	Am	243	Dysprosium	Dy	162.50
Antimony	Sb	121.75	Einsteinium	Es	253
Argon	Ar	39.95	Erbium	Er	167.26
Arsenic	As	74.92	Europium	Eu	151.96
Astatine	At	210	Fermium	Fm	255
Barium	Ba	137.34	Fluorine	F	19.00
Berkelium	Bk	249	Francium	Fr	223
Beryllium	Be	9.01	Gadolinium	Gd	157.25
Bismuth	Bi	208.98	Gallium	Ga	69.72
Boron	B	10.81	Germanium	Ge	72.59
Bromine	Br	79.91	Gold	Au	196.97
Cadmium	Cd	112.40	Hafnium	Hf	178.49
Calcium	Ca	40.08	Helium	He	4.003
Californium	Cf	249	Holmium	Ho	164.93
Carbon	C	12.01	Hydrogen	H	1.008
Cerium	Ce	140.12	Indium	In	114.82
Cesium	Cs	132.91	Iodine	I	126.90
Chlorine	Cl	35.45	Iridium	Ir	192.2
Chromium	Cr	52.00	Iron	Fe	55.85
Cobalt	Co	58.93	Krypton	Kr	83.80

Element	*Symbol*	*Atomic weight*	*Element*	*Symbol*	*Atomic weight*
Lanthanum	La	138.91	Rhenium	Re	186.2
Lawrencium	Lw	257	Rhodium	Rh	102.91
Lead	Pb	207.19	Rubidium	Rb	85.47
Lithium	Li	6.94	Ruthenium	Ru	101.07
Lutetium	Lu	174.97	Samarium	Sm	150.35
Magnesium	Mg	24.31	Scandium	Sc	44.96
Manganese	Mn	54.94	Selenium	Se	78.96
Mendelevium	Md	256	Silicon	Si	28.09
Mercury	Hg	200.59	Silver	Ag	107.87
Molybdenum	Mo	95.94	Sodium	Na	22.99
Neodymium	Nd	144.24	Strontium	Sr	87.63
Neon	Ne	20.18	Sulfur	S	32.06
Neptunium	Np	237	Tantalum	Ta	180.95
Nickel	Ni	58.71	Technetium	Tc	99
Niobium	Nb	92.91	Tellurium	Te	127.60
Nitrogen	N	14.01	Terbium	Tb	158.92
Nobelium	No	253?	Thallium	Tl	204.37
Osmium	Os	190.2	Thorium	Th	232.04
Oxygen	O	16.00	Thulium	Tm	168.93
Palladium	Pd	106.4	Tin	Sn	118.69
Phosphorus	P	30.97	Titanium	Ti	47.90
Platinum	Pt	195.09	Tungsten	W	183.85
Plutonium	Pu	242	Uranium	U	238.03
Polonium	Po	210	Vanadium	V	50.94
Potassium	K	39.10	Xenon	Xe	131.30
Praseodymium	Pr	140.91	Ytterbium	Yb	173.04
Promethium	Pm	145	Yttrium	Y	88.91
Protactinium	Pa	231	Zinc	Zn	65.37
Radium	Ra	226.05	Zirconium	Zr	91.22
Radon	Rn	222			

LIST OF CHEMICALS AND CHEMICAL COMPOUNDS

Acetic acid CH_3 $COOH$
Alcohol CH_3 CH_2 OH
Alizarin S C_{17} H_9 O_4 • $2NaHSO_3$
Alkali Na OH
Alpha-pinene C_{10} H_{16}
Alum Al $K(SO_4)_2$
Alumina Al_2 O_3
Aluminum potassium sulfate Al $K(SO_4)_2$
Ammonia NH_3
Ammonium chloride NH_4 Cl
Ammonium ferro-cyanide
(NH_4) Fe $(CN)_6$ • $6H_2O$
Ammonium molydbate $(NH_4)_2$ Mo O_4
Anhydrous iron oxide Fe_2 O_3
Anhydrous sodium carbonate Na_2 CO_3
Aqua regia $HNO_3 + HCl$
Barium chloride Ba Cl_2
Bicarbonate HCO_3
Calcium carbonate Ca CO_3
Calcium chloride Ca Cl_2
Calcium hydroxide Ca $(OH)_2$
Calcium oxide Ca O

Calcium phosphate $Ca H_4 (PO_4)_2 \cdot H_2O$
Camphor $C_{10} H_{16} O$
Carbon dioxide CO_2
Carbon disulfide CS_2
Carotene $C_{40} H_{56}$
Casein formaldehyde CH_2O plus milk protein
Celluloid $(-C_6H_9O_5-)_x (NO_3)_y + XC_{10} H_{16} O$
Cellulose nitrate $(-C_6H_9O_5-)_x (NO_3)_y$
Cellulose zanthate $(-C_6H_9O_5CS_2Na-)_x$
Collofion $(-C_6 H_9 O_5-)_x (NO_3)_y$
Copper chloride $Cu Cl_2$
Copper iodide $Cu_2 I_2$
d-Camphor $C_{10} H_{16} O$
Dimethylglyoxime $(CH_3 CNOH)_2$
Diphenylcarbazide $(C_6 H_5 NH \cdot NH)_2 CO$
Ethanol $CH_3 CH_2 OH$
Ether $(C_2 H_5)_2 O$
Ethyl acetate $CH_3 CO_2 \cdot C_2 H_5$
Eugenol $C_6 H_3 (C_3 H_5) (OCH_3) \cdot OH$
Ferric ammonium sulfate $Fe (NH_4 SO_4)_3$
Ferric chloride $Fe Cl_3$
Ferric thiocyanate $Fe (CNS)_3 \cdot 3H_2O$
Ferrous sulfate $Fe SO_4$
Fluorescein $C_{20} H_{12} O_5$
Hydrochloric acid HCl
Hydrochloric tin $Su Cl_2$
Hydrogen peroxide $H_2 O_3$
Hydrogen sulfide H_2S
Lead acetate $Pb (CH_3 COO)_2$
Lead chloride $Pb Cl_2$
Lead chromate $Pb Cr O_4$
Lead iodide $Pb I_2$
Lead nitrate $Pb (NO_3)_2$

Lead oxide	$Pb\ O$
Ligroin	$Cn\ H_{2n+2}$
Lycopene	$C_{40}\ H_{56}$
Lycoxanthine	$C_{40}\ H_{56}\ O$
Magnesium chloride	$Mg\ Cl_2$
Magnesium sulfate	$Mg\ SO_4$
Malachite green	$3C_{23}\ H_{25}\ N_2\ Cl \cdot 2Zn\ Cl_2 \cdot 2H_2O$
Manganese dioxide	$Mn\ O_2$
Manganese nitrate	$Mn\ (NO_3)_2 \cdot NS\ (OH)$
Methanol	$CH_3\ OH$
Methylene blue	$[(CH_3)_2\ N]_2\ C_{12}\ H_6$
Mica	$3Si\ O_2 \cdot H_2O$
Nickel ammonium sulfate	$Ni\ SO_4\ (NH_4)_2\ SO_4$
Nitric acid	HNO_3
Nitrocellulose	$(\ -C_6\ H_9\ O_5\ -)_x\ (NO_3)_y$
Petroleum ether	$C_6\ H_{14}$
Phellandrene	$C_{10}\ H_{16}$
Phenolphthalein	$C_{20}\ H_{16}\ O_4$
Phosphomolybdic acid	$20Mo\ O_3 \cdot 2H_3\ PO_4 \cdot 48H_2O$
Platinum black	Pt
Polyvinyl chloride	$[-\ CH_2\ CHCl\ -]_n$
Potassium bromide	KBr
Potassium chloride	KCl
Potassium chromate	$K_2\ Cr\ O_4$
Potassium ferrocyanide	$KFe\ (ON)_6 \cdot 3H_2O$
Potassium hydroxide	KOH
Potassium iodide	KI
Potassium nitrate	KNO_3
Potassium nitrite	KNO_2
Potassium permanganate	$KM_n\ O_4$

Potassium thiocyanate	$KCNS$
Pyrites	$Fe\ S_2$
Quinone	$CO\ (CHCH)_2\ CO$
Resorcinol	$C_6\ H_4\ (OH)_2$
Rubeanic acid	$SC\ (NH_2)\ C\ (NH_2)\ S$
Safrole	$CH_2\ O_2{:}\ C_6\ H_3 \cdot CH_2 \cdot CH{:}\ CH_2$
Silver nitrate	$Ag\ NO_3$
Sodium bisulfite	$Na\ HNO_3$
Sodium bitartrate	$Na\ HC_4\ H_4\ O_6 \cdot H_2O$
Sodium carbonate	$Na_2\ CO_3$
Sodium chloride	$Na\ Cl$
Sodium dichromate	$Na_2\ Cr_2\ O_7 \cdot 2H_2O$
Sodium ferricyanide	$Na_3\ Fe\ (CN)_6 \cdot H_2O$
Sodium ferrocyanide	$Na_4\ Fe\ (CN)_6 \cdot 10H_2O$
Sodium hydroxide	$Na\ OH$
Sodium peroxide	$Na_2\ O_2$
Sodium phosphate	$Na\ H_2\ PO_4$
Sodium potassium carbonate	$Na\ KCO_3$
Sodium rhodizonate	$C_6\ O_6\ Na_2$
Sodium salicylate	$HOC_6H_4\ COONa$
Sodium sulfate	$Na_2\ SO_4$
Sodium sulfide	$Na_2\ S$
Sodium thiosulfate	$Na_2\ S_2\ O_3 \cdot 5H_2O$
Stannous chloride	$Sn\ Cl_2$
Strontium chloride	$Sr\ Cl_2$
Sulfuric acid	H_2SO_4
Sulfurous acid	SOH_2
Tannic acid	$(HO)_3\ CH_2 \cdot CO_2 \cdot C_6\ H_2\ (OH)_2\ CO_2H$
Tartaric acid	$CO_2\ HCOH_2\ COH_2\ CO_2H$
Tin chloride	$Sn\ Cl_2$

Titanous chloride	$Tn\ Cl_2$
Vinyl chloride	$CH_2\ CHCl$
Zinc ammonium sulfate	$Zn\ SO_4 \cdot (NH_4)_2 \cdot 6H_2O$
Zinc chloride	$Zn\ Cl_2$

GLOSSARY

(Meanings explained here are only for the use of the word in this book.)

AGAR-AGAR, or AGAR (*n.*): a substance similar to **gelatin.**

ALKALI (*n.*): a chemical compound that forms salts when combined with acids.

ALKALINE (*adj.*): having the **properties** of an **alkali.**

ALLOY (*n.*): an intentional mixture of two or more chemical elements having metallic **properties.**

ANALYSIS (*n.*): the examining of a chemical compound or other substance to determine all possible facts about it. ANALYTICAL (*adj.*): of or having to do with **analysis.**

BEAKER (*n.*): a wide glass container used in chemical laboratories.

CALORIE (*n.*): the amount of heat required to raise the temperature of one **gram** of water one degree **centigrade.**

CATALYST (*n.*): a substance that causes a chemical change when it is added to another substance but is not changed itself.

CELLULOSE (*n.*): a substance with complex molecules found in wood, cotton, and other plants. It consists of **polymerized** sugar molecules and is used in making **synthetic** products.

CENTIGRADE (*n.*): a temperature measure in which water is said to freeze at 0 degrees and boil at 100 degrees.

CENTIMETER (*n.*): a measure of length in the **metric system.**

CHROMATOGRAPHY (*n.*): the separation of mixtures into their various parts by the use of some material such as **filter** paper which absorbs the different parts in different ways.

CRUCIBLE (*n.*): a small dish in which chemicals can be heated to high temperatures.

CUBIC CENTIMETER (*n.*): a measure of volume in the **metric system.**

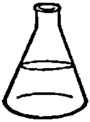
ENZYME (*n.*): a substance originating from a living cell that acts as a **catalyst** in such processes as the digestion of food.

EVAPORATE (*v.*): change a liquid into a vapor.

EXTRACT (*v.*): remove a compound or element from another compound or substance.

FILTER (*n.*): a material through which mixtures of liquids and solids are passed to achieve their separation. FILTER (*v.*): pass the liquid through such material.

FLASK (*n.*): a small bottle with a narrow neck used in chemical laboratories for mixing or heating liquids.



GELATIN (*n.*): a soft, gummy substance used in food, medicine, and chemistry.

GRAM (*n.*): a measure of weight in the **metric system.**

HYPOTHESIS (*n.*): an idea or theory that is tested to determine whether it is true or false. HYPOTHESES: more than one **hypothesis.**

INSULATION (*n.*): a material that prevents electricity or heat from passing to another material. INSULATE (*v.*): separate or cover with **insulation.**

ION (*n.*): an atom or molecule that has an electrical charge.

LITER (*n.*): a measure of volume in the **metric system.**

M (*n.*): short form for Molar, which is a measure of the proportions of chemicals and water in a **solution.**

METER (*n.*): a measure of length equal to 100 **centimeters** in the **metric system.**

METRIC SYSTEM (*n.*): a worldwide system of weights and measures based on the gram for weight and the **meter** for length. Larger or smaller measures are made by multiplying or dividing these units by 10, 100, 1,00, etc.

MILLILITER (*n.*): a measure of volume in the **metric system.**

MOLASSES (*n.*): a thick brown liquid produced during the manufacture of sugar.

MORTAR AND PESTLE (*n.*): a bowl and a kind of stick with a rounded end, used to crush solid material.

N (*n.*): short form for Normal, which is a measure of the proportions of chemicals and water in a **solution.**

pH (*n.*): an expression of the proportion of **alkali** to acid in a **solution.** An alkali has a pH of more than 7; an acid has a pH of less than 7. A solution that has a pH of exactly 7 is neither acid nor alkali.

PIGMENT (*n.*): the chemical compounds in an object or substance that give it color.

POLYMER (*n.*): a compound of high molecular weight produced by joining many different kinds of molecules. POLYMERIZATION (*n.*): the process of producing a **polymer.**

PRECIPITATION (*n.*): the process by which a solid separates from the liquid in which it is dissolved. PRECIPITATE (*n.*): the solid substance resulting from **precipitation.**

PROPERTIES (*n. pl.*): the characteristics of an element or compound.

RADIOACTIVE (*adj.*): sending forth energy in the form of rays resulting from the breaking apart of atoms.

REACTION (*n.*): a chemical change.

REAGENT (*n.*): a substance used in chemical **analysis.**

SATURATE (*v.*): dissolve the greatest possible amount of a solid substance in a **solvent.**

SOLUBLE (*adj.*): capable of being dissolved in a liquid. A substance that can be dissolved is said to have **solubility.**

SOLUTION (*n.*): a chemical mixture consisting of one or more substances dissolved in a liquid.

SOLVENT (*n.*): a substance used to dissolve other substances or compounds.

SPECIALIZE (*v.*): study one particular part, product, or process of a profession.

SYNTHETIC (*n.*): a product made by compounds formed by chemical **reaction** in a laboratory, rather than by natural origin.

TEST TUBE (*n.*): a small glass tube, closed at one end, used in chemical laboratory work.

VACUUM (*n.*): a space, as in a bottle or other container, from which most of the air has been removed.

YEAST (*n.*): a substance used in baking.

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